Vehicle Dynamics Investigation Using a Hydraulic Hardware-in-the-Loop Test-Rig

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Introduction

In this contribution a new design for a hydraulic Hardware-in-the-Loop (HIL) test-rig is presented. The purpose of the test-rig is to investigate the performance of active suspension systems, such as Active Roll Control (ARC) or Active Dynamic Control (ADC) from TRW Automotive Inc. The design is focused on achieving a flexible test-rig capable of various experimental setups with maximum possibilities for data acquisition. The test-rig should also be compact and transportable.

For the safety of the passengers and the avoidance of damages to the vehicle, the operation and performance of this system has to be monitored together with a fault detection strategy, both for the components as well as for the system. Lately by using signal and/or model-based fault detection the number of sensors for this purpose have been minimized while at the same time an improved system monitoring and fault isolation has been realized. Due to the high safety requirements this process must be realized in real-time. Extensive simulations as well as experimental tests should be realized in order to validate the system model and also to define the normal and abnormal operations of the system.

Hardware-in-the-Loop methods allow the system to be tested in a simulated but experimental environment. Systems or components, which are usually in interaction with an environment or another system to be examined, can be replaced by models calculated on a real-time processor. This contributes to the goal of achieving suitable control algorithm and/or improved reliability under real operational conditions. The benefits are a decrease in the development time and costs as well as higher product quality.

The Active Suspension Control System (ASCS) [1] developed by TRW Automotive Inc. is based on an electro-hydraulic system which is used - to reduce the roll angle of the vehicle and improve the comfort in case of Active Roll Control (ARC), - to change the dynamic behavior of the vehicle in order to improve its handling and comfort in case of Active Dynamic Control (ADC), or - to combine the advantages of both systems with Active Dynamic Control II (ADC2) dependent on the arrangement of the actuators. The system is actuated by hydraulic cylinders attached between the anti-roll bar and the chassis as seen in Fig. 1. The hydraulics is supplied by electro-hydraulic valves and pump.

To ensure a safe and reliable operation, the system and its components have to be monitored continuously during their operation. Beside sensor and communication faults, the mechanical components also can cause faults, which are more difficult to detect. These faults can be that a valve sticks in a certain position or that a hydraulic hose is disconnected or leaks.

Test-Rig Design

The main idea of the HIL test-rig is to apply the original hardware to be considered in interaction with the simulated environment. Therefore a real-time hardware is necessary to realize environments interaction [2].

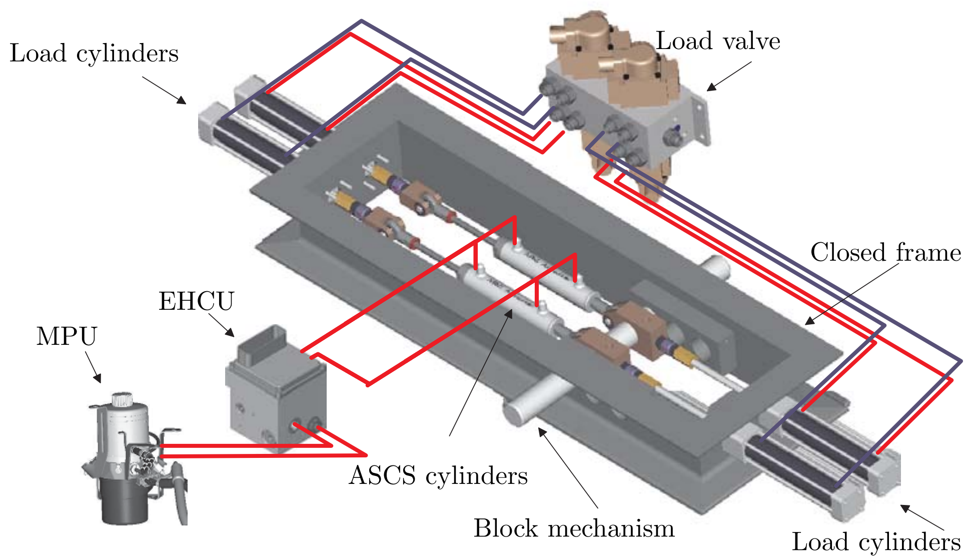

Figure 1: Detailed illustration of the test-rig assembly

In order to keep the forces isolated on the test-rig a closed frame approach was selected as shown in Fig. 1. This approach has the benefit that the test-rig can be mounted on any kind of platform, since it does not transfer any force to its surrounding. In Fig. 2, the principal structure of the HIL is illustrated. The real hardware is in continuous interaction with the dSPACE system which simulates the vehicle dynamics. The forces on the actuators of the ASCS calculated from the simulation program are forwarded to a load controller which in its turn controls the load valve supplying hydraulics to the load cylinders. The complete test-rig states are measured and fed back to the simulation program to be used for the continuing vehicle dynamics calculations. Parallel to this, an ASCS controller controls the Hydraulic Control Unit (HCU) to supply hydraulics to the ASCS cylinders.

The load cylinders are mounted from the outside of the frame. During the operation of the system, the unevenness of the road and the chassis movement are realized by forces from the load cylinders acting to the ASCS cylinders, hence the test-rig must be capable of generating forces from both sides of the cylinder.To realize the full systems motion, the test-rig consists of two rows each with three cylinders coupled in series. The two outer cylinders generate forces from the road and the chassis simulations to the real hardware (HIL) ASCS cylinders. The dSPACE system used for simulation of vehicle dynamics, simulates the different driving maneuvers and in interaction with a load controller supplying hydraulics to the load cylinders in order to generate the desired forces on the system. Simultaneously, the vehicle model and the ASCS controller control the ASCS valve block to generate the needed hydraulic reaction forces.

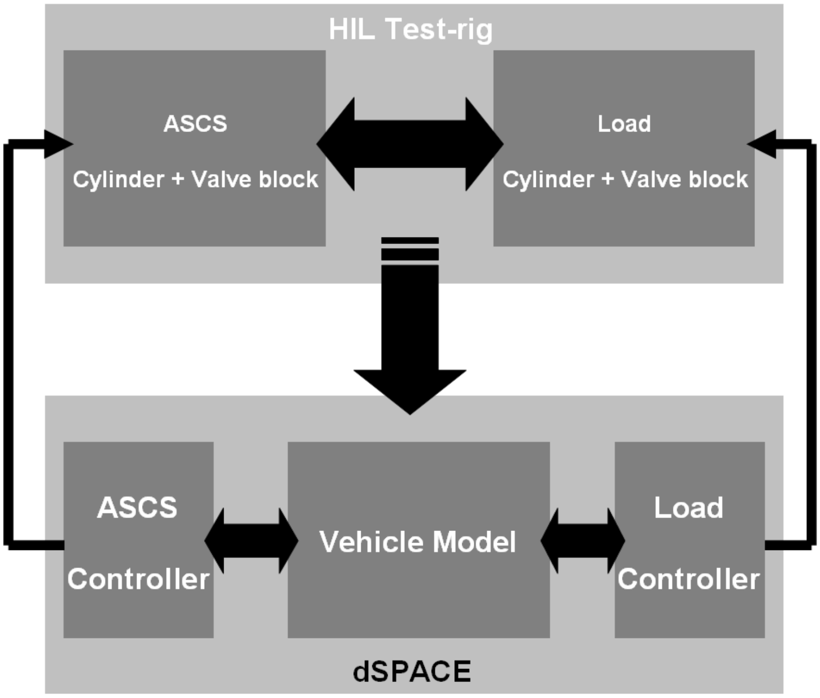

Figure 2: HIL test-rig system schematics

Having a maximum of data acquisition capabilities is one of the main design objectives. This is realized by using the data available from the system itself and by installing additional sensors on the test-rig. The hydraulic flow to the ASCS is supplied by a Motor-Pump-Unit (MPA) and an Electro-Hydraulic-Control-Unit (EHCU) which also provide information such as motor current, oil temperature, pump speed, valve current and system pressure. Using additional sensors, information about the forces acting between the cylinders, the cylinder piston travel and the cylinder chamber pressures are obtained.
Another objective of the test-rig design is the flexibility between various experimental setups. Therefore, the test-rig is designed to allow the ASCS cylinder to be affected from one side only by the load cylinder. This is realized by designing a blocking mechanism which locks the ASCS cylinders bottom to the test-rig frame, hence redirecting the forces from the second load cylinder into the frame instead of the ASCS cylinder. By using aluminium coupling elements and installing hose guides, the moving mass and resistance of motion is minimized.

Conclusion

The Hardware-in-the-Loop test-rig makes it possible to monitor the systems operation under "real"conditions and environment. This is crucial for the development of a fault detection and fail-safe strategy.
In order to detect different kinds of faults, sensors are needed to measure the appropriate quantity at the appropriate position. Increasing number of sensors contributes to increasing amount of cables and processing equipment. This in turn decreases the overall reliability of the system. Another consequence would be increasing cost of the system which is not desirable [3]. So a conflict appears between technical functionality, reliability, production cost and safety requirements, which has to be solved. To detail systems overall behavior as well as to validate interval dependencies, HIL-experiments are used.
Model-based fault detection methods applying observers for state estimation or using parity equations can be used simultaneously to detect faults in actuators, the system and sensors [3]. The mechanical faults are not easy to reproduce and analyze during systems operation in the vehicle, since the environmental influence to the system is not definable and also because of the hazards involving generating faults on the system. Using a HIL test-rig enables the possibility to validate the system model used for fault detection and also to perform experiments in a safe environment with defined conditions.
In a parallel work [4], the design of model-based estimation technique is used in order to minimize the hardware respectively the sensors. The introduced test-rig concept gives for different ASCS controllers and hardware an optimal experimental tool for validating those advanced techniques with respect to technical and safety relevancies.

References

1. Kesselgruber, D., Aktive Wankregelung zur Steigerung von Fahrsicherheit und Lenkagilität, Tagung Fahrwerktechnik (lecture), Haus der Technik, München, Germany, 2003.
2. Nissing, D., Identifikation, Regelung und Beobachterauslegung für elastische Großhandhabungssysteme, VDI Verlag, Düsseldorf, Germany, 2002.
3. Isermann, R., Überwachung und Fehlerdiagnose: Moderne Methoden und ihre Anwendungen bei technischen Systemen, , VDI-Verlag, Düsseldorf, Germany, 1994.
4. Kashi, K. and Söffker, D., Model based estimation of internal and external forces on a hydraulic cylinder, proc. SIM 2003, accepted (to be published), 2003.
5. Kesselgruber, D., Zur analytischen Modellbildung und schätzerbasierten Überwachung von PKW Bremssystemen, Shaker Verlag, Aachen, Germany, 2001.
6. Nissing, D. and Kesselgruber D.,. Erprobung von realen aktiven Fahrwerkregelsystemen im virtuellen Fahrzeug. Simulation und Simulatoren - Mobilität virtuell gestalten, VDI-Berichte 1745. Düsseldorf: VDI. 281-301. (in German), 2003.