Hardware in the loop simulation technology evaluation method for power steering systems

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Abstract. In the paper, the method of measuring and assessing of steering systems with the help of test benches with HILS technology implementation is justified in part of the adaptive algorithms of the regulation of the assistant steering torque. In the article, overall principal of creating virtual – physical system using as a physical part the rack and pinion steering system with electromechanical assistant is described. Interaction of the physical and virtual parts and fields of usage are described. Development, calibration and tweaking of the newly designed ECU and adaptive algorithms suppose a lot of testing. Time consumption and difficultness can be reduced only by the way of carrying out bench tests with usage of HILS technology.

1. Introduction
Adaptive systems take significant part in the development of automotive industry nowadays. In particular chassis adaptive systems and algorithms develop swiftly. Adaptive systems provide increasing of active safety of the vehicle (steering and stability) and also help to provide necessary road comfort. Adaptive steering system has been actively used recently. Parameters of this system depend on external factors such as: velocity and lateral acceleration of the vehicle, acceleration and torque of the steering wheel. Up-to-date algorithms of assistance control of the power steering work based on the changes of these parameters. Adaptive algorithms development begins in the early stage of chassis design where the necessity of functional, control and calibration testing of the steering system appears.

The aim of this paper is to establish the necessity of development and research of the adaptive algorithms and components with the help of hardware in the loop (HIL) technology.

2. Results
There are several methods of testing the adaptive algorithms in the following test bench course of development:

1) Test benches with the software in the loop simulation (SILS) technology. Such test benches allow to simulate operation of the algorithm of the steering system in the composition with the virtual multibody model of the vehicle with the electrical interface and with control units. Such benches are used for functional, control and calibration testing of the electrical blocks and units of the steering system.

2) Test benches with the hardware in the loop simulation (HILS) technology. This type of test benches consists of physical and virtual parts. The physical part represents a steering system with all components in the vehicle configuration and loading apparatus of the test bench. The virtual part represents mathematic multibody model of the vehicle and driver. Such test benches allow functional, control, calibration testing of the steering system and its mechanical and electric components separated. Interaction of the physical part of the test bench (steering system) and virtual part (mathematical multibody model of the vehicle) is provided by means of the electronic control unit (ECU) and CAN interface by the feedback (sensor signals).

In this article composition, fields of application and advantages of test benches designed according to HILS technology are described. These types of test benches now are the most promising decisions for
testing the full assembled steering system and the most sought after. The principal architecture of the virtual-physical testing of the steering systems is shown on the scheme below in Figure 1.

![Figure 1. Flowchart of the test bench and its components: SW – steering wheel, SC – steering column, SM – steering mechanism, E/MA – assistant electric motor which can be installed both on SC and on SM, ECU – electronic control unit, A1, A2 – left and right actuator of the test bench, Fr – rack force, Xr – rack position, SR – steering robot, α_{sw} – SW angle, ω_{sw} – SW rotation velocity, Tsw – torque applied to the SW.](image)

The physical part of the system appears as steering system assembled and loading apparatus. Steering system consists of the steering mechanism with the electric assistant, ECU of the steering assistant, steering column (SC) and steering wheel (SW). The system is connected mechanically with the loading apparatus – actuators of the tie rods and steering robot. Virtual part of the system represents a multibody model of the vehicle which includes mathematical description of the dynamic model of the vehicle with not less than 94 degrees of freedom. Components of the vehicle and its systems represent a set of bodies with linear and non-linear connections. Also the virtual part contains interaction of the vehicle and the environment [1].

The ECU plays the key role in the operation of this system which interchanges information with the torque sensors and angle sensor of the SW, vehicle speed, lateral acceleration via CAN bus. The desired assistant torque is calculated based on these signals and transferred to the loading electric motor, which implements this assistant effort. This ECU also interchanges information with the mathematical model of the car via CAN bus. Synchronization of the physical and virtual parts of the system is carried out by the loading apparatus A1, A2, SR. They also send the feedback signals which are the signals of the sensors: Fr, Xr, α_{sw}, Tsw. Feedback signals come in the virtual part of the system and provide the control of the virtual vehicle. The load cycle which is the control signal for the driver model forms the Tsw, α_{sw}, ω_{sw} that SR implements [2].

List of signals necessary for test bench operation:
- control signals: α_{sw}, ω_{sw}, Tsw, CAN signal from mathematical model to the ECU
- feedback signals: Fr, Xr, α_{sw}, Tsw, CAN signal from the ECU to the mathematical model
- additional signals: ε_{sw} – angular acceleration of the SW, Vi, ar – velocity and acceleration of the steering rack.

As a characteristic example of the test bench designed with HILS technologies usage for testing the full steering system IPG Automotive test bench is shown in Figure 2 below.
This type of test benches has advantages over traditional test benches since they possess wider functionality:

1) It becomes possible to determine the mutual influence of each component on the characteristic of the whole steering system.
2) It becomes possible to model standard and non-standard testing (functional, calibration, road imitation, operational, resource testing).
3) Increased safety is provided unlike the road tests.
4) High repeatability of any test is provided due to the control system and the control of the feedback.
5) Acceleration of tests in comparison with the road tests.

Disadvantages of the HIL test bench:

1) High cost (expensive mechanical and software components).
2) High complexity of implementation.
3) High energy costs.
4) Requires specially trained staff.

Application area:

1) Steering systems with the rack SM with mechanical connection between the SC and SM. Permissible tie rod force no more than 30 kN.
2) Steering systems with the rack SM without mechanical connection between the SC and SM. Permissible tie rod force not more than 30 kN.
3) Potentially possible to use for steering systems with other types of SM. Tie rod force less than 30 kN.

Testing possibilities of the HILS test bench:

1) Bench testing of the components separated and assembled with the whole steering system.
2) Road testing of the virtual car with the real steering system in accordance with regulations: GOST 31507-2012 «Road vehicles. Handling and stability. Technical requirements. Test methods », ISO 4138, ISO 7401 and other.
3) Carrying out non-standard road tests, non-standard maneuvers, imitation of the malfunction of the steering assistant, interaction of the electromechanical power steering adaptive algorithm with the electronic chassis systems such as ESP (Electronic stability program), ABS (Anti-lock braking system) and others.
4) Car driving simulations on digitized roads.
5) Potentially it is possible to carry out the forced durability testing considering influence of the adaptive ECU algorithms.
6) Different versions of the adaptive algorithms and ECUs.
7) Testing of the steering system components with different characteristics.
8) Functional validation of the steering system.
9) Subjective evaluation of the steering sensitivity can be available with the connection of the drive simulator (Figure 3) [3].

![Figure 3. Interaction of the test bench and drive simulator with feedback.](image)

3. Conclusion
HILS technologies are widely used by the vehicle and part manufactures for virtual bench testing to speed up and reduce the cost of the manufacturing nowadays.

The usage of HILS test benches allows different testing of the steering systems and its components in real time with high repeatability. It helps to research the components interaction with the mathematical model of the vehicle and models of the vehicle electronic systems.

Creation of this test bench for NAMI is a topical task. It will allow characterization testing of the steering components and steering systems assembled, steering tuning, calibration of the adaptive steering algorithms of the steering assistance, validation of the components and steering system.

References
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