HYDRAULIC CIRCUIT CONTROL OF A STEER BY WIRE SYSTEM

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Abstract

The future of cars will be connected with "by-wire" systems. The Technical University of Liberec, Department of Vehicles and Engines has developed a design of testing equipment for directional control system testing. The objective of the newly designed equipment is to incorporate a wheel with a real tire and a flexible mounting of axle components.

The paper describes properties and control of the hydraulic circuit consisting of two double-acting engines with a unilateral piston rod and two proportional valves (Parker D1FP). Each of the front axle wheels is controlled separately. The paper illustrates relationships and potential of steer-by-wire systems at the experimental equipment. The safe and easy control of a vehicle undoubtedly poses significant requirements. Satisfying them and improving the design to enhance the vehicle's stability have always belonged to the primary objectives of designers. Consequently, the chassis characteristics, the mechanical features of wheel suspensions, the quality of air suspensions, but also speed control (including brakes) and the vehicle's directional control have always been emphasised. The objective of the paper was to design a steer-by-wire directional control mechanism with a suitable arrangement. The comparison focuses on various design options to arrange the action members (actuators) of this mechanism.

Keywords: *steer by wire, hydraulic circuit, control*

1. Introduction

The safe and easy control of a vehicle undoubtedly poses significant requirements. Satisfying them and improving the design to enhance the vehicle's stability have always belonged to the primary objectives of designers. Consequently, the chassis characteristics, the mechanical features of wheel suspensions, the quality of air suspensions, but also speed control (including brakes) and the vehicle's directional control have always been emphasised. The last century brought the development of control systems especially in the aviation industry where any potential failures usually lead to fatal catastrophes. Presently, so called wire technologies are being discussed in the context of the vehicle's control as well. The current legislation (inter alia 1968 Vienna Convention) has so far not enabled a complete substitution of a driver with an automatic system. Certain exceptions have been authorized by the CARS 21 expert group within the European Union, e.g. the automatic systems (so called Advanced Assistance Systems) that may fully take over the vehicle control immediately before a collision when the driver is not likely to respond on time, and at very slow speed (below 10 $km \cdot h^{-1}$).

Future developments may result in vehicles with „an autopilot“, so while driving, the driver will either be allowed to have a rest or do something else. However, the current organization of the road transport does not make the autopilot implementation possible. The launch of the system will obviously be linked with the vehicle position identification, the navigation system development and with the higher precision GPS or the European Galileo System. Surveying precision and speed will be critical for such systems and their automatic control. For this reason, the launch of the vehicle automatic directional control can be expected first on primary routes - on specific parts of highways with heavy traffic and a potential for the construction of additional radars identifying the current vehicle position. Consequently, vehicles will have to undergo a transformation too. At present, car producers together with their suppliers have focused intensively both on the development of new systems and improvement of the existing ones. Both traditional groups and so called assistance systems which are supported by new forms of communication and in certain cases enable adaptation to new conditions are involved. The assistance system group includes inter alia: currently used vehicle stabilization systems (ESP – Electronic stability program), systems monitoring the vehicle surroundings, e.g. adaptive cruise controls (ACC – Adaptive Cruise Control) and e.g. newly introduced systems monitoring the driver’s alertness (DAM – Driver Alertness Monitoring, DSC – Driver Status Monitoring) etc.

The development is concentrated on launching new board networks to handle (from a technical point of view) a lot of information coming to the vehicle from various systems. For example, at present, experts are intensively working on the board network called FlexRay (which stands for Flexible Ray). The transmission system has unique addressing and bus accessing. The message exchange is based on the communication cycle and clocking which is common for all bus nodes and components. The network features high transmission speeds, enhanced interference immunity and two independent channels for each unit.

Future development of the directional control of vehicles will be closely connected with steer-by-wire systems or the steering of the vehicle by means of an electric wire which is to replace a mechanical link between the steering wheel and wheels. It is a control system whose input signal is a movement of the steering wheel, this impulse is converted into an electrical variable, it goes to an action member and it responds accordingly – by turning the wheels at a relevant angle into a specified direction. The steer-by-wire system can be generally categorized in accordance with various viewpoints. The first one can be a link between the wheels which offers two basic options. The first is a traditional control of both the wheels simultaneously by one actuator which moves the tie rod and turns both wheels at the same time. The other is a separate turning of each wheel, i.e. each directionally controlled wheel has its own actuator which will initiate the turning.

A test bench was developed to test the steer-by-wire system properties. The test bench is described in „Action of Force in Steering Mechanisms of Vehicles in an Experimental Laboratory Establishment“.

2. The steer-by-wire test bench hydraulic circuit

Currently, the hydraulic circuit of the vehicle’s directional control test bench consists of two double-acting hydraulic cylinder with a unilateral piston rod (dia. 32 mm/22 mm) and two proportional valves (D1FP Parker, the rate of flow of 3 $dm^3 \cdot min^{-1}$ at the pressure gradient of 3.5 MPa) located on a body which houses a pressure valve, a relief valve and other accessories. The DF Plus proportional valve features very good dynamic properties allowing a frequency range between 0-400 Hz at –3 dB and 350 Hy with a phase shift of –90°. Pressure liquid comes from a gear hydraulic generator with internal tooting driven by a single-phase motor. A hose interconnects the pressure liquid source and the body with the proportional valves. Steel tubes establish a connection between the proportional valves and the hydraulic cylinders. An air oil cooler is built into a return line. The hydraulic circuit uses the HM46 oil.

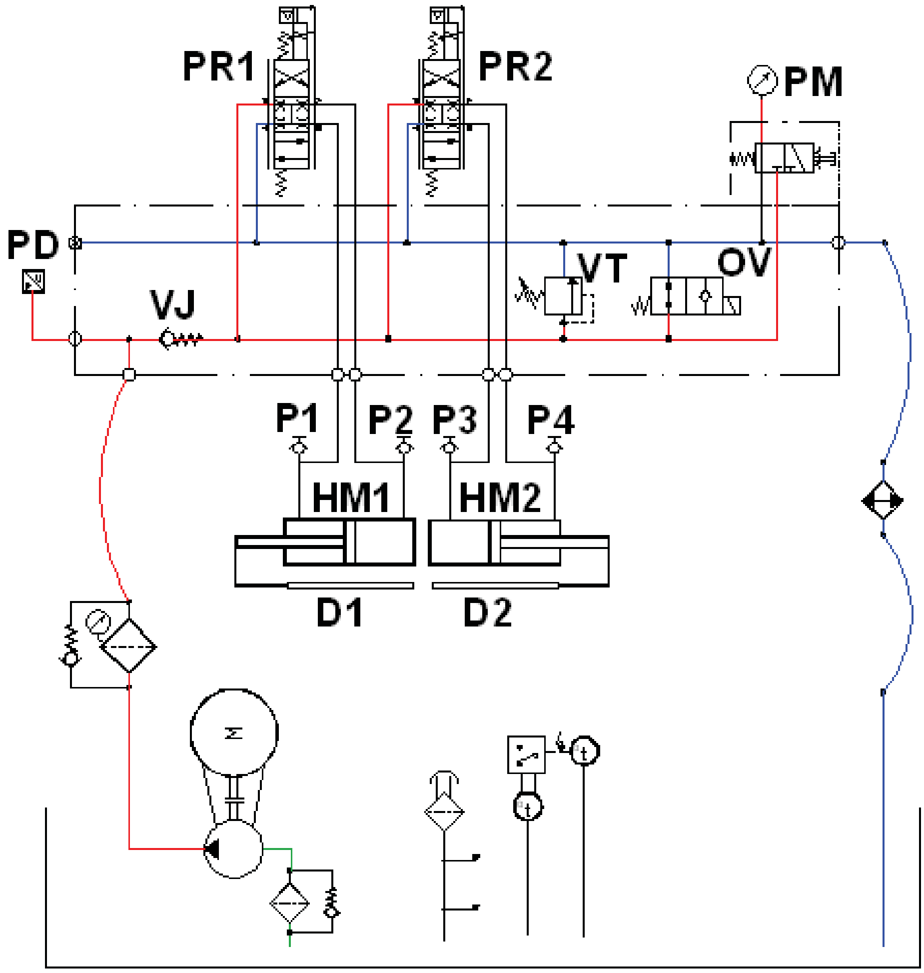

Fig. 1. Hydraulic Circuit Layout

Tab. 1. Hydraulic Circuit Components

Hydraulic Circuit Components	Designation
Electric motor	M
Pump with internal toothing	
D1FP PARKER Proportional Valve	PR1, PR2
Connecting body	
PARKER One-way valve	VJ
PARKER Relief Valve	OV
PARKER Safety Valve	VT
PARKER Pressure Gauge	PM
PARKER Digital Pressure Sensor	PD
PARKER Hydraulic Cylinder	HM1, HM2
P6A Hottinger Pressure Sensor	P1, P2, P3, P4
LM 10 Renishaw	D1, D2

3. System control

An MF624 input-output card by HUMUSOFT s.r.o. acting jointly with the Matlab/SimulinkReal/Time Toolbox program was used to control the hydraulic circuit. In this program, an application obtaining information about the current position of the DF Plus proportional valves are created. By means of the LM10 linear incremental sensor the application receives information about the current position of the hydraulic cylinders – an indirect measurement of the wheel's angle. The information is processed in the application of the mentioned program and then a relevant setting of the DF Plus proportional valves is calculated.

The elimination of a rigid bond between the steering axle wheels offers a number of options for the setting of the combined extent of the inner and outer wheel angles. The required criteria can for example incorporate:

The same angles of the inner and outer wheel directional deflection

a) The identical inner and outer wheel angles.
b) The outer wheel is turned more than the inner one – i.e. a fast cornering results in a higher angle of the directional deflection on the outer wheel compared to the one on the inner wheel (a higher tire cornering force is acting on the outer wheel, which significantly increases the directional stability).

The obtain information about the system's properties, the paper outlines the system's responses to a sudden command (a transitional characteristic) for the extension of the action member of the inner and outer wheel by 25 mm. This value of the action member extension roughly corresponds to a steeering wheel turning of 180 degrees and a driver is able to achieve the change approximately within one second while passing through the so-called „Moose test“ at a speed of 50 km/h. The vaules are obtained from real practical tests with Škoda Roomster. The PID control was used for controlling the members.

From the viewpoint of the wheel steering control connection there are two basic variants:

a) each wheel is steered separately,
b) one wheel acts as a master, the other wheel (a slave) follows it.

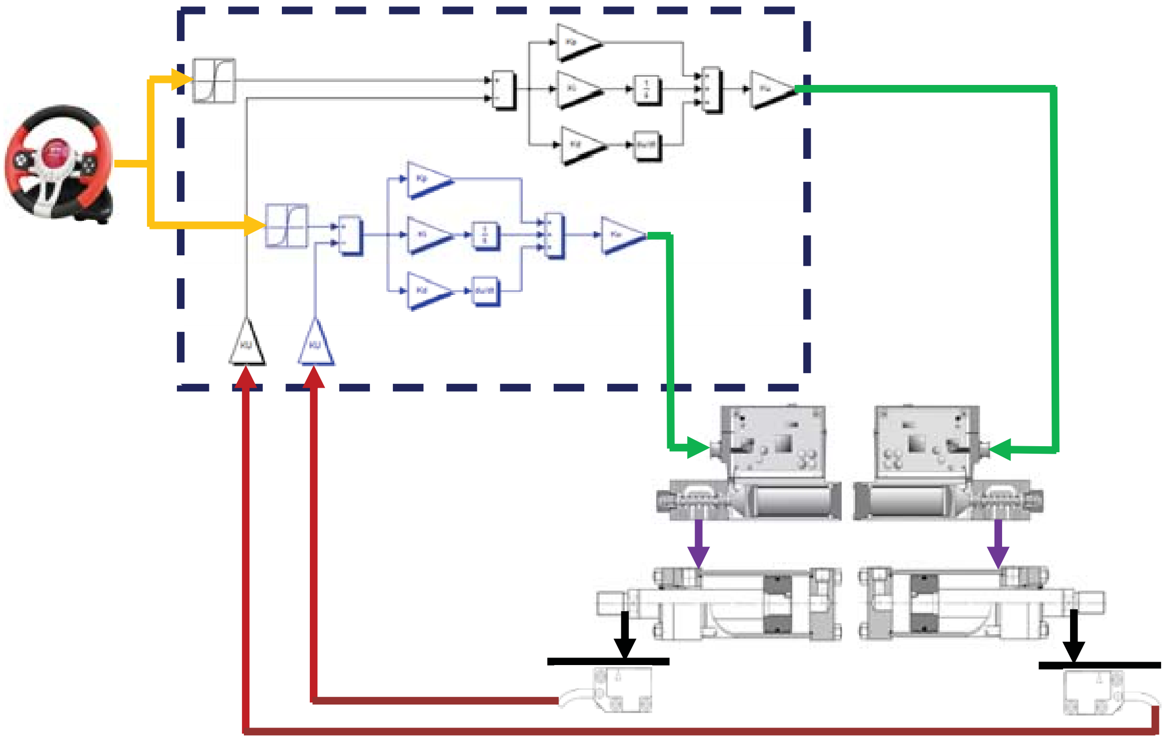

Fig. 2. Steering control layout – each wheel controlled separately

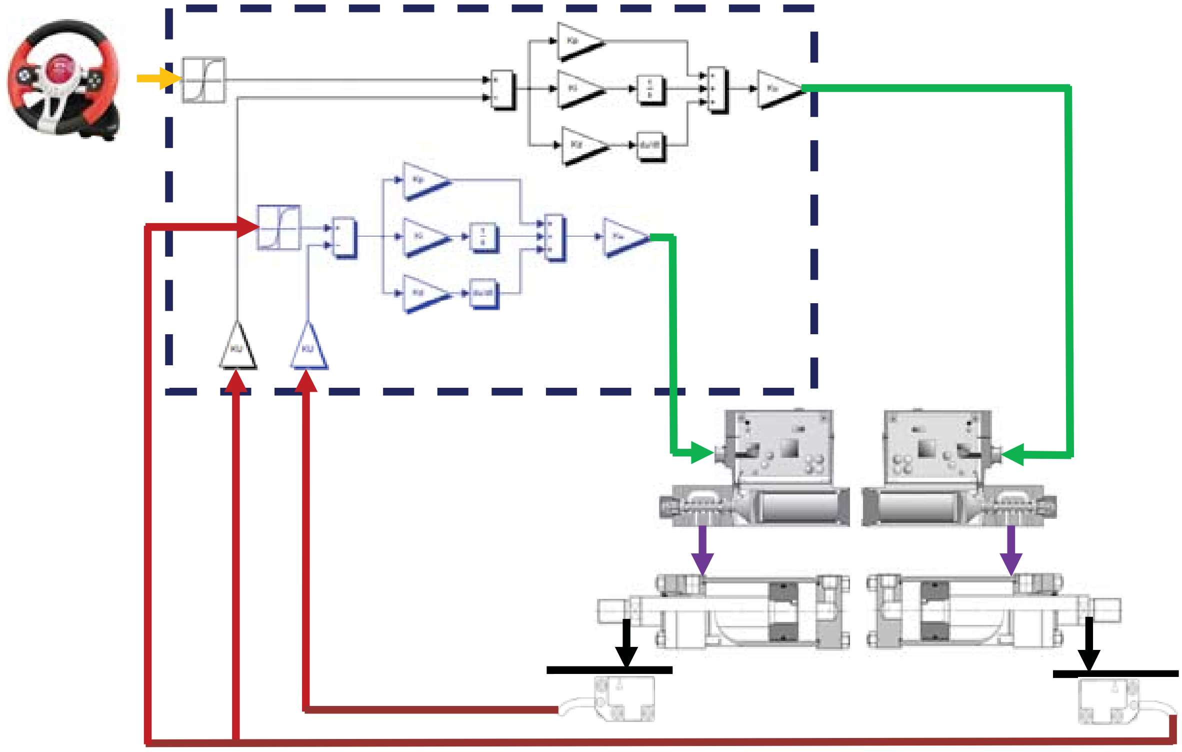

Fig. 3. Steering control layout – one wheel as a Master, the other one follows as a slave

4. Measured values

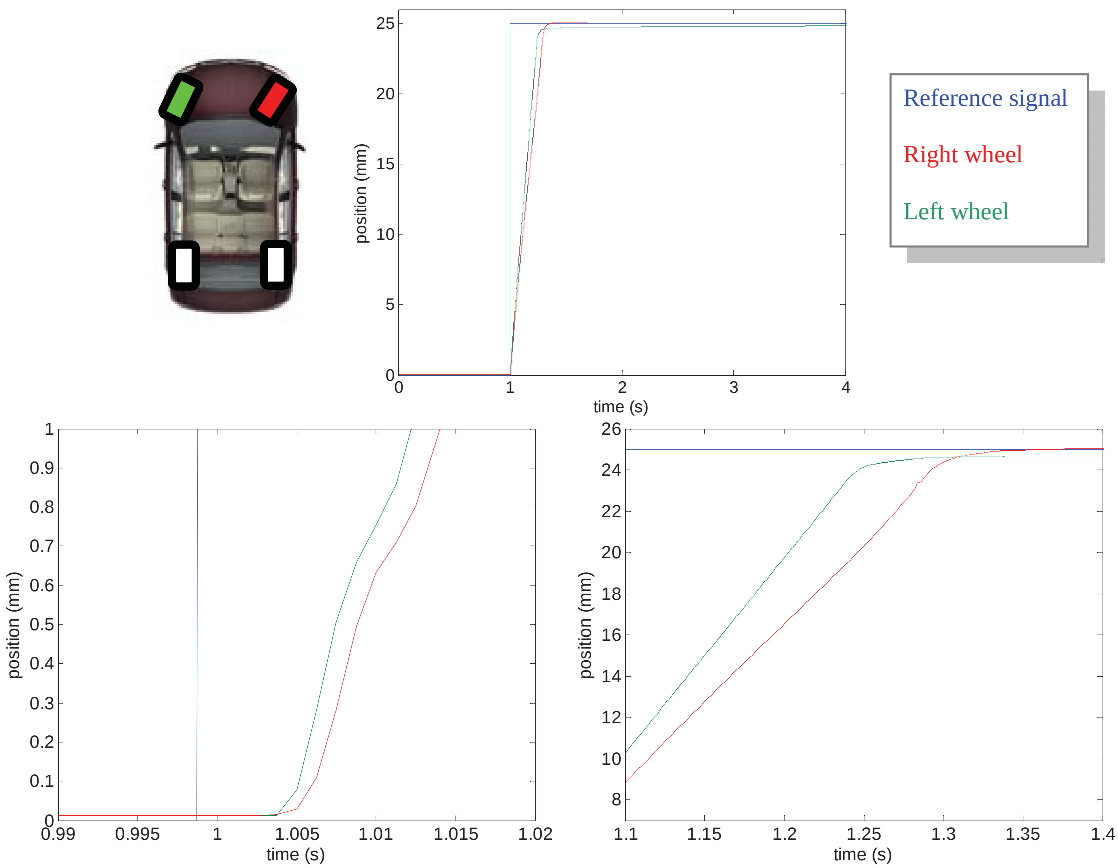

Fig. 4. Directional control action member extension pattern – each wheel controlled separately

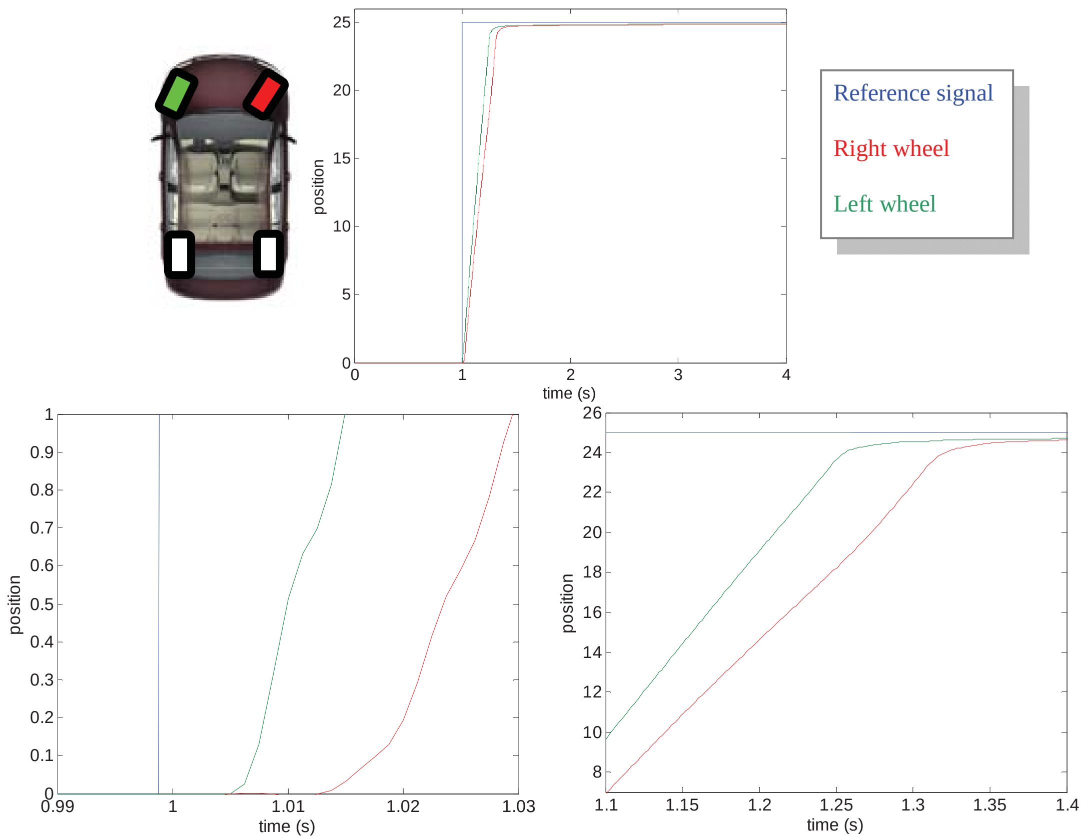

Fig. 5. Directional control action member extension pattern – the left wheel as a master, the right follows it as a slave

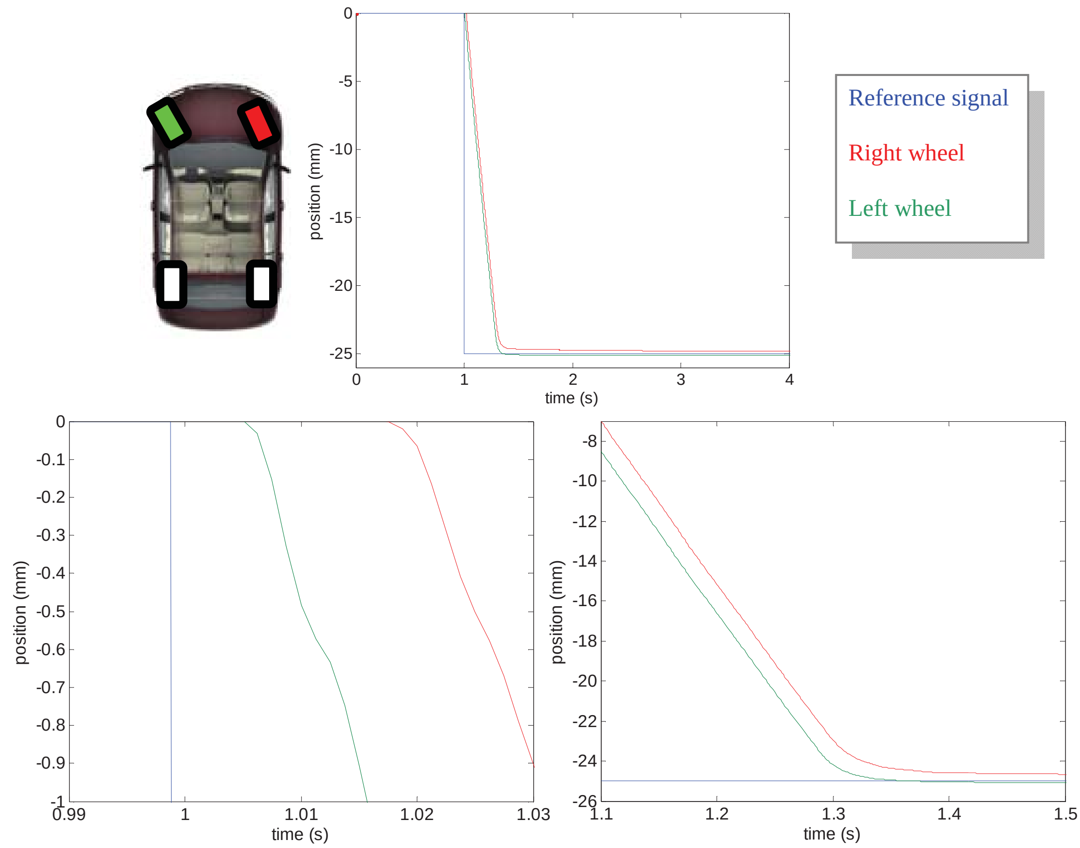

Fig. 6. The directional control action member extension pattern – the left wheel as a Master, the right one follows it as a slave

The measurement was conducted on a McPherson axle which is used in Škoda Roomsters. The pressure on mats under individual wheels was set at 3.5 kN. A BRIDGESTONE EK300 195/55 R15 tyre was mounted on the wheel rim.

The extension value of 0.1 on an action member approximately corresponds to 0.07 degree of the steering wheel turning (as calculated from the Škoda Roomster) and a wheel angle of 0.042 degree (specified by parameters of the directional control used for the same vehicle).

The values of the individual components of the PID control were chosen to eliminate overshooting of the wheel angles. The system time lag (the control unit – action member) where both the wheels were controlled independently is 0.003 s. The system start-up time is about 0.2 s and it is impacted by max. opening of the installed valves. In the other type of the system (Master/Slave) the reference wheel shows the same properties as the first system. The slave wheel starts responding later by another 0.01 s than the reference (master) wheel. The system start-up time is identical with the first system. The system of independent wheel control offers a higher level of accuracy than the Master/slave system.

5. Conclusion

The objective of the paper was to design a steer-by-wire directional control mechanism with a suitable arrangement. The comparison focuses on various design options to arrange the action members (actuators) of this mechanism. The first phase investigates the properties of the electric and hydraulic arrangement, where each steered axle wheel has its own actuator for the setting of a wheel angle. An electromechanical system for wheel turning is being prepared for the next phase of the project. Currently, to complete a by-wire laboratory system, a sensor-equipped steering wheel is being worked on. The initial setting of parameters for control unit constants will be carried out before real vehicle driving tests. The control unit will obtain information from relevant sensors and issue commands for a proper setting of the action members.

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