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Intelligent steering

When analyzing modern multiaxial central axle trailers with large-volume wheels, it is clear a steering system of at least one axle is inevitable. Hydraulic positive steering systems and self-steering systems are synonymous with insuperable disadvantages and limited in their functionality. With this in mind, an electro-hydraulic all-wheel steering system was developed in which all axles are steered independently of each other. The resulting possible steering strategies such as the "in track mode" or "crab steering" allow an application-specific steering mode resulting in an improvement of the maneuverability, protection of the soil and plants and less tire wear.

Keywords

Electro-hydraulic control, drawbar trailer, liquid manure trailer, steering system

Abstract

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Positive steering systems as well as self-steering systems are widely used in practice. However, both steering systems have got system related disadvantages. Using the self-steering system large forces are diverted into the tractor via the steering cylinder due to the hydraulic positive displacement principle. In addition, an excessive wear of the tires due to friction cannot be excluded because of the fixed steering ratio. Self-steering systems with one free axle tend to be unstable at high speed. Furthermore, the self-steering system has to be blocked for reversing. An electro-hydraulic steering system does not have any of these disadvantages and may provide additional functionalities. In collaboration with Kotte Landtechnik GmbH, an electro-hydraulic all-wheel steering system (**Figure 1**) has been developed at the University of Applied Sciences Osnabrück as a steer-by-wire-solution for drawbar trailers. The following functional goals were focused on:

- standardized interface to the tractor (ISO 26402)
- CAN-bus interface to other service systems
- self-sufficient system for all drawbar trailers
- improvement of the driving behavior
- no tire wear due to friction
- additional steering functions (e.g. crab steering)
- licensable steering system

System description

The main input parameter for the whole electro-hydraulic steering system is the drawbar angle sensor between the towing vehicle and the trailer. Using the measured drawbar angle, the turning angle of the wheels is calculated with the help of a vehicle model and given to the single axles as a set point. **Figure 2** shows the block diagram for the steering system. The set point that is calculated for every axle is the parameter for an electro-hydraulic position control loop [1].

By means of an individual control of the single axles, the electro-hydraulic all-wheel steering system allows different steering strategies that are shortly explained in the following text.

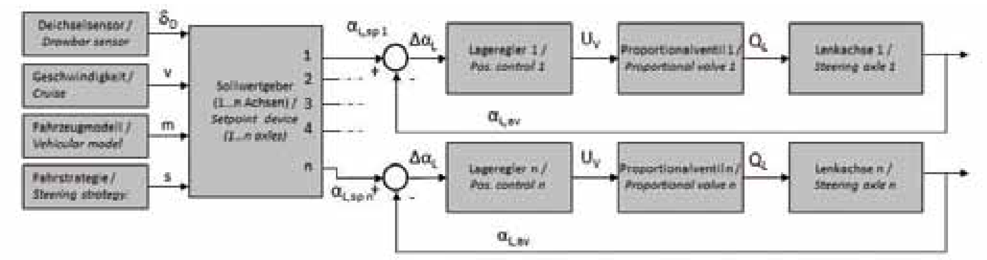
In track mode

The highest priority concerning the "In track" mode is the protection of the plants. In this mode, the trailer follows exactly the track of the towing vehicle. Due to this, the tractor/trailer combination is especially maneuverable and the tire wear is reduced to a minimum. This steering strategy is particularly suited for driving in small alley ways on the field, used for fertilizing or applying pesticides. This is due to the fact that a damage of the nearby crops caused by the wheels of the trailer is prevented.

Fig. 1

Elektro-hydraulic steering system implemented in an eight wheeler

Fig. 2



System structure

Crab steering

The main focus of the off-set track driving, the crab steering, is placed on minimal compression of the soil. Due to the uniform deflection of the wheels, the trailer leaves the track of the towing vehicle so that every wheel uses its own track, spreading the total load on several tracks.

Slope drift

Trailers with hydraulic positive steering systems tend to glide down when driving parallel to a slope. The slope drift function provides a possibility for the vehicle drivers to pass difficult sections safely with the help of an automatic uphill countersteering.

Self-steering system/positive steering system

In this steering strategy, the vehicle is driven with one blocked axle. In contrast to the conventional hydraulic positive steering system, no fixed steering ratio is used. The steered axles are aligned to the instantaneous center of rotation at all times, reducing tire wear. Due to the blocking of one axle the driving behavior is, especially concerning the steering, comparable to other steering systems and the driver does not have to adjust to it.

All axles centered

In addition, the axles of the trailer can be blocked in neutral position (driving straight ahead). Here, the value of the drawbar sensor is not considered, so that e.g. straight reversing is easily possible [2].

Function trial and drawbar angle sensor

The central element for the implementation of the electro-hydraulic all-wheel steering system in the functional model was a "Rapid Control Prototyping System" (Matlab/Simulink and DSpace-Box). With this, the system configuration, the programming and the test drives have all been conducted within only a few months. The test drives were made with the functional model on a test track, including different characteristics (bumps, potholes, slalom). The measuring track (**Figure 3**) shows the vehicle's behavior in the "In track" mode on the circuit. The positive drawbar angle in bend 1 results in negative steering angles at the steering axles 1 and 2. The trailer runs without tire wear in the track of the rear axle of the towing vehicle. When reaching the end stop of the axle 2, the strategy "In track" mode has to be left. To maintain the rolling motion of the wheels without any tire wear due to friction, the axle 2 has to stay fully deflected and the axle 1 has to be steered back, if the drawbar angle gets bigger. Furthermore, it is essential for a rolling motion of the wheels without tire wear due to friction that small alterations to the drawbar angle cause an immediate change for the set point position of the wheels. This results in the special importance for the faultless measurement of the drawbar angle [1].

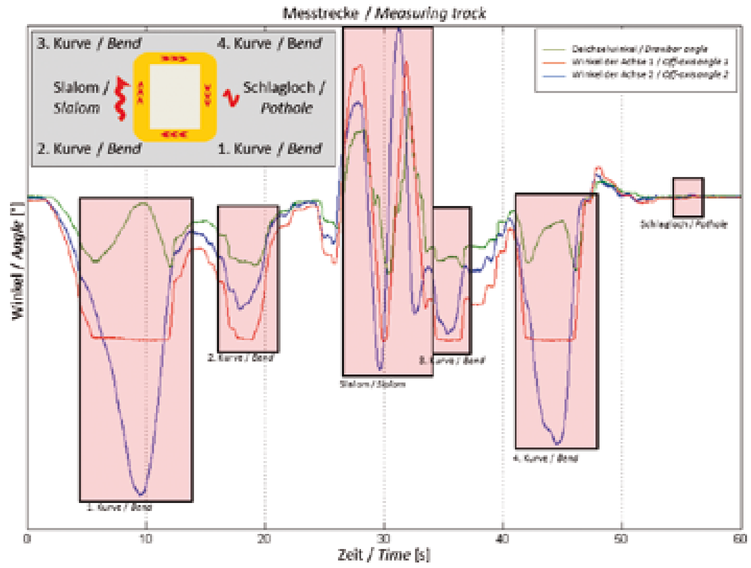
The identification of the drawbar angle was initially carried out with the help of a drawbar angle sensor. A disadvantage for the eccentrically placed sensor unit is the strong influence of nodding and rolling movements resulting from this position (**Figure 4**).

For this reason, a drawbar sensor was developed that decouples the nodding and rolling movements mechanically. To do so, the drawbar is connected to the towing vehicle via the usual K80 ball. Using a joint polygon, a steering trapeze is installed, which is held up by the standardized K50 connection on the left and right of the K80 ball as well as another K50 ball in the middle of the drawbar (**Figure 5**). An additional transverse trapeze is used as a pivot point for the drawbar angle sensor. Thus, the drawbar angle sensor is always located in the plane of the joint polygon whereupon the drawbar of the trailer can nod and roll freely around the K80 ball [1].

Process of the serial certification

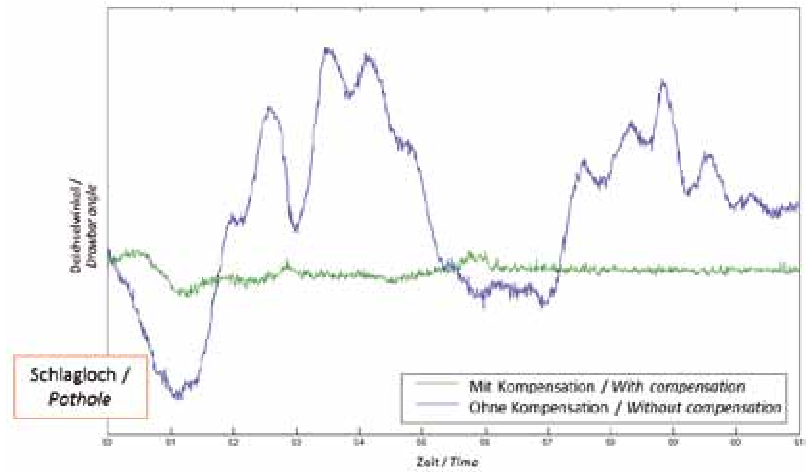
After a successful functional development and testing, the serial certification, in compliance with the functional safety, was the focus of the development. This was conducted in collaboration with the TÜV Nord Mobilität and concluded in January 2010 with a variant independent approval for road use according to ECE-R 79 (**Figure 6**). The development process was organized according to ISO 25119. This generic standard for safety-related parts of control systems for tractors and machinery for agriculture and forestry concerns the whole safety life cycle beginning from the initial idea of the product to its decommissioning.

Fig. 3



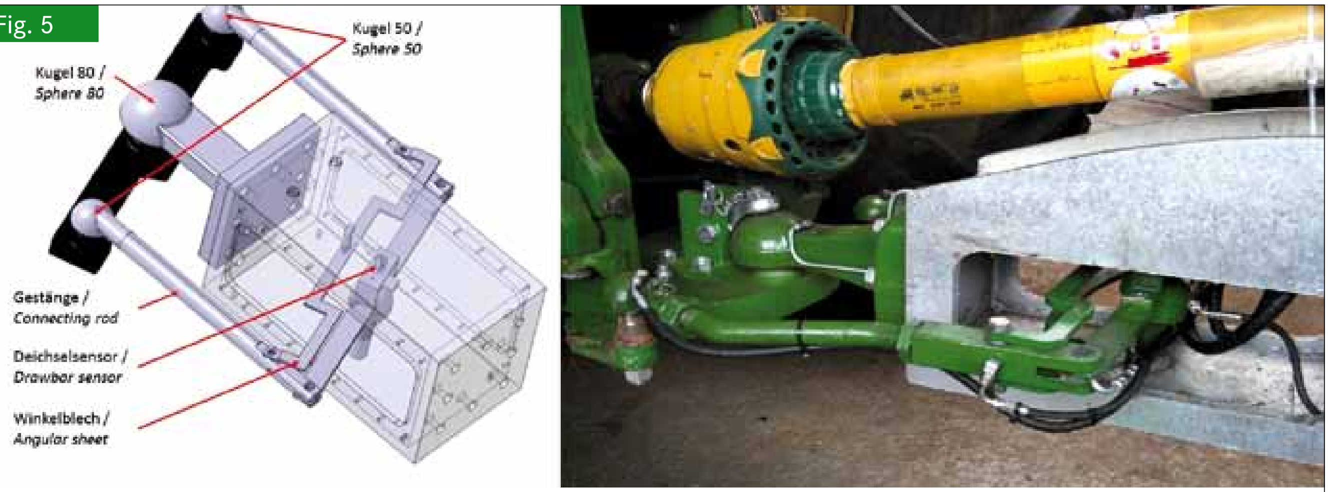
Measuring track with nodding and rolling compensation [1]

Fig. 4



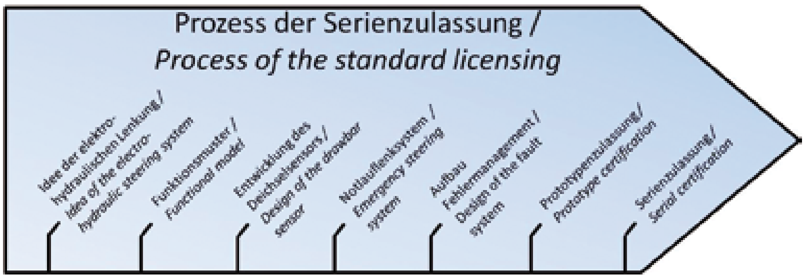
Comparison: with and without nodding and rolling compensation [1]

Fig. 5



Drawbar sensor [1]

Fig. 6



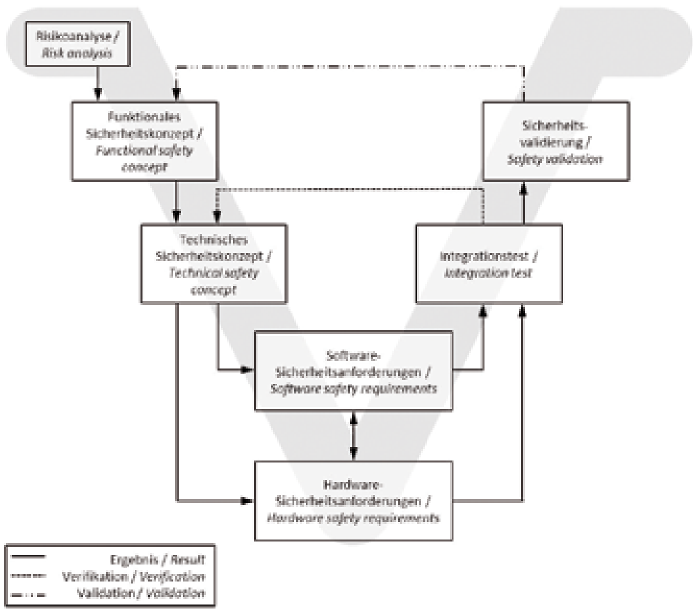
Main sections of the development of the electro-hydraulic steering system

Already in the concept phase, a hazard and risk analysis was conducted which identified all potential hazardous situations and determined the most dangerous situations using structured valuation guidelines. These are crucial for the classification of the "Agricultural Performance Level" (AgPL) which provides development directives and principles reducing the risk of a malfunction to a minimum. The all-wheel steering system is classified as Agricultural Performance Level c.

The standard requires a systematic approach according to the acquainted V-model, which is shown in **Figure 7** for the structuring of the safety requirement. Initially, superior requirements are methodically developed on the left side of the model before they are specified in the safety concept. To exemplify this, the development of the drawbar sensor can be mentioned. In this case, the functional procedure is to ensure the function, i. e. the measurement of the angle between tractor and trailer. The technical implementation concretizes the requirements and provides the incorporation of a redundant sensor as well as a value range check. Additionally, the response times and the system behavior in case of an error are defined. These requirements are considered as input values for the hardware and software that are also developed according to the V-model. The faultless implementation of the mentioned sub-goals is warranted with the integration test and safety validation. For this, the goals from the respectively opposite specification phase are classified as the basic principle of the examination.

The hardware is designed according to category 2 of the ISO 25119. This prescribes a control of the input and output signals as well as the control of the logic unit by a second controller. All single components meet the high claims in terms of the reliability (MTTF and B_{10}) and are tested with regard to all environmental influences occurring in the vehicle, comparable to the environmental testing according to IEC 60068-2. The testing of the system components regarding to the electromagnetic com-

Fig. 7



Structuring of safety requirements according to [3] patibility (EMC) was made with the help of component tests according to PREG 95/54/EG and ECE R10-02.

All phases of the software life cycle are developed according to SRL 1 (software requirement level). Additionally, a certified programming language and environment were used, which is classified as the safety integrity level 2 (SIL2) according to [4; 5]. Small and manageable software modules with minimal access rights to data and defined parameters made a structured software module test possible, this was, amongst others, conducted with a boundary value analysis and a walkthrough.

Emergency steering and fault system

In case of an error (e. g. tear-off of the hydraulic or electric energy), an emergency steering system was developed that converts the electro-hydraulic steering system into a self-steering system. A steering axle which is blocked over a centering unit takes the control of the track guiding. At that time, the other axles are set into floating position. Test runs of the emergency steering system with the loaded and unloaded trailer gave information about the driving performance. The focus of this test was on the dynamic effects on the vehicle during the transition from the active electro-hydraulic steering to the passive self-steering system. For the electro-hydraulic steering a fault system in several parts was developed. The different conditions were classified according to the severity of the error into a green, yellow and red status. This was visualized in the serial control as a "traffic light display". The status green represents the faultless condition of the system. Moderately severe errors such as the exceeding of the maximum speed in the field modus are classified as yellow. In this case, a change from the actual steering strategy to another one that is permitted in road traffic is activated. Serious errors (status red) induce the above mentioned transition from the active electro-hydraulic steering to the passive self-steering system.

Conclusions

Since 2010, the electro-hydraulic all-wheel steering system has a serial certification and is the first system of its kind allowed to be used in road traffic. This is a system which can be adjusted flexibly concerning the number of axles as well as the vehicle geometry (length of drawbar, distance of axles, maximal steering angle). The modularity of the system is increased due to the use of a CAN-bus interface.

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