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Method for the improvement of the road behaviour of fast running tractor-implement-combinations

Due to the steady increase of traveling longer distances with tractors, vehicle dynamics are becoming more and more important. The research activities presented here show an approach for improving the lateral dynamic behavior of tractors with heavy duty implements mounted at the rear. This can be done by decoupling the implement and tractor in combination with intelligent implement movements during cornering. The method was investigated during extensive road trials, which verified the positive effect.

Keywords

Tractor, vehicle dynamics, vehicle dynamics control system, driving safety

Abstract

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The maximum speed of agricultural tractors has increased continuously over the last decades, while the vehicle masses as well as the implement masses are constantly growing. Thus it is obvious that the physical limits of the vehicle dynamics are closer to being reached. Due to the huge moment of inertia of these tractor-implement-combinations, the tyres have to apply large lateral forces while cornering. If the adhesion limit is exceeded here, the vehicle is no longer controllable. Therefore new considerations concerning the active improvement of driving safety and driving comfort of tractors with heavy duty implements are required.

Methodical approach

The previous activities to improve the vehicle behaviour of tractors were mostly aimed towards the vertical vehicle direction. In comparison, methods to affect the behaviour in the lateral direction still offer huge potential for improvement.

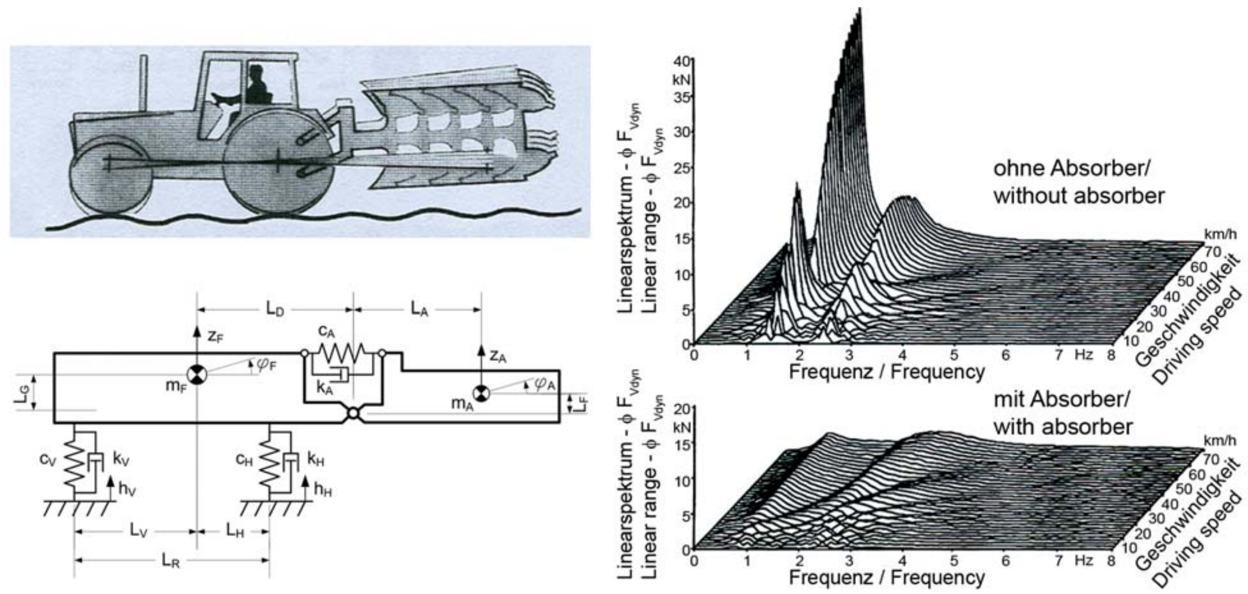
The idea to use the comparatively large implement masses to affect the vehicle behaviour in a positive way during transport rides is not a new one. In [1] this was done by a non-rigid coupling of the implement (**figure 1**). Thanks to the spring-/damper element mounted in the coupling area, the mass of the implement can now be used as an absorber mass. The resulting vibration absorber leads to a reduction of the pitching oscillations. Therefore especially at the front axle, the dynamic wheel loads are reduced by 80 % in unsuspended vehicles. The result is an increase of the steerability and therefore an increase of the driving safety. This idea to decouple the masses of tractor and implement was taken up in the presented research activities and an additional degree of freedom around the vertical axis was introduced (**figure 2**). Due to the relative motion that is now possible, a distinction can be made between the yaw movement of the tractor and the yaw movement of the implement. An acceleration of the vehicle, as a result of steering activities, does not necessarily lead to an acceleration of the implement mass.

According to the current state of the art, the described relative movement can be realized with little constructive effort. The three point hitch, in combination with the lateral stabilizers at the lower links, already provides the necessary degree of freedom. At present, hydraulic lateral stabilizers are being used to switch between the floating and the rigid coupling of the implement. However, during driving on roads, the coupling must always be rigid. These stabilizers can ideally be used as actuators in the presented system, which extends their functionality.

To ensure defined relative movements of the implement, the development and the assembly of a control system is necessary. In doing so, the generation of the required reference values represents the major challenge. Therefore the main development objectives are defined in the following:

- Reducing the yaw moment, i.e., decrease of the lateral forces that need to be applied by the tyres
- Reducing the rolling of the tractor, by a displacement of

Fig. 1



Method to reduce the pitch oscillations [1]

the implements centre of gravity

- Following of the implement in the tractors lane to minimize the occupied space
- Ensuring the predictability of the system behaviour by the driver and other road users
- Considering the subjective security feeling

Based on the formulated objectives, a real system has been chosen as a model for the desired system behaviour. This system is the trailer, which is assumed to have optimal behaviour. The result is that the implement will always execute the movements that a trailer coupled to the tractor would show, and is limited only by constructive constraints.

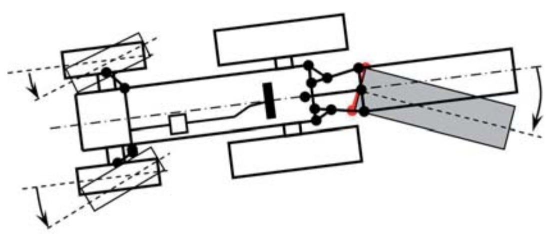
Design of the control system

Figure 3 depicts the basic design of the control system. Different kinds of sensors provide the needed input values. On the one hand, this is the actual position of the implement with respect to the tractor. This value is calculated from the stroke of the hydraulic lateral stabilizers. On the other hand, the steering angle is measured at the front axle and the current vehicle states such as driving speed, lateral acceleration and yaw rate are recorded. Suitable filter functions are used to reduce the measurement noise as far as needed.

As mentioned before, the calculation of the reference values is based on the model of a trailer. This model generates the reference values in real-time that correspond to the movements a trailer coupled to this tractor would perform in the current driving situation. The hydraulic controller is designed to achieve a fast and above all a good damped dynamic behaviour. The sensors can only measure the vehicle states after these have occurred. However, it is necessary that the implements movements are executed in synchronization with the current vehicle movements. Therefore a predictive observer was used in this control system, which is able to estimate future vehicle states out of the current vehicle states and the measured steer angle.

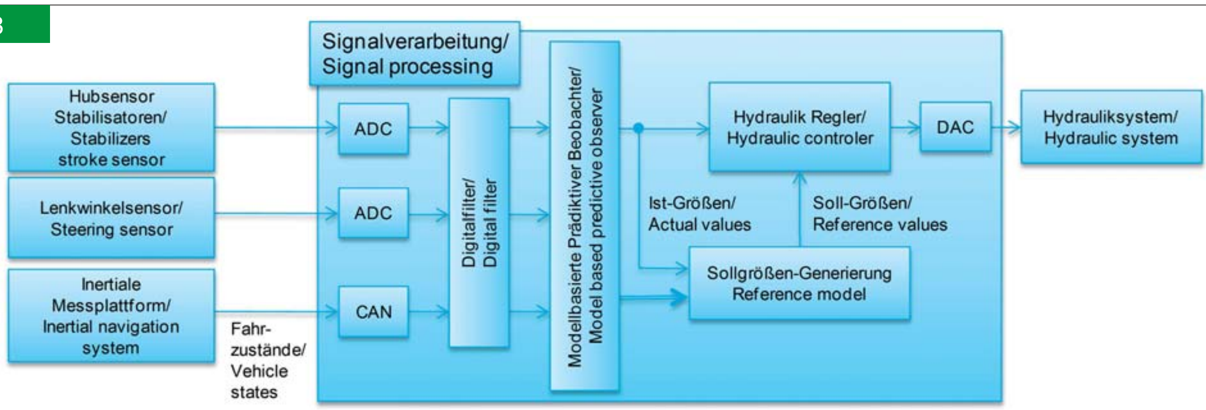
This calculation is done with the so-called linear single track model, which represents a mathematical formulation of the vehicle behaviour [2]. The single track model provides a simple way to describe the lateral vehicle dynamics and is widely used in the automotive industry, for example, Electronic Stability Control (ESC). However, this standard description is not valid for driving speeds below 50 km/h [3], because the influence of the dynamic tyre behaviour cannot be ignored at these low velocities. Therefore, this model approach had to be adapted for use with agricultural tractors [4]. Thanks to the predictive approach, it was possible to achieve a time window that is large enough to have the movements of implements occur at exactly the right time.

Fig. 2



Visualisation of the basic idea

Fig. 3



Schematic representation of the control system

Practical road tests

To analyse the developed system under practical conditions, a demonstrator vehicle was built up. For this, a tractor-implement combination was equipped with actuators, sensors and devices for signal processing. The selected road tests are based on standards from the automotive industry, which had to be adapted to the requirements of heavy mobile machinery. All of the tests were performed using the control system and as a reference, with a rigid mounted implement.

The steer step is one of the most commonly used tests in the field of lateral vehicle dynamics. In this test, which begins with straight driving at a constant speed, the steering wheel is suddenly moved to a certain position. The steering wheel is held in this position until a stationary state is reached. According to the standard, this steering angle must result in a stationary acceleration of 4 m/s^2. The steer step is appropriate to determine parameters and to gain objective statements over steerability, because the influence of the driver is minimized.

Figure 4 shows that the vehicle reaction, in this case the yaw rate, has a steeper rise when the control system is used. This corresponds with a more direct vehicle behaviour. To quantify this reaction, among others, the so-called response time can be determined. This was done according to the corresponding standard. Thanks to the use of the control system, the response time could be reduced by 15% in this test. This is an enormous improvement in the field of lateral dynamics.

Another important test is the double lane change (**figure 5**). This test simulates avoiding a suddenly appearing obstacle, and afterwards the vehicle must quickly swerve back to avoid oncoming traffic. A test is interpreted as a success, if not a single pylon has been hit. Compared to the steer step test, this test allows more subjective findings, since the driver has a far bigger influence on the test results. However, the test delivers important information about the steerability and the stability of the investigated vehicle.

The test was carried out with different drivers and all of the drivers pointed out two things: First, the controlled system had a more direct response when steering out of the first and the second lane. This confirms the results of the steer step test. Second, the controlled system had a more stable behaviour and thus the vehicle was more controllable. This becomes apparent in the second lane and especially in the third lane, which is the most critical part of the test.

In addition, the measurements gained during the tests verify these subjective impressions. Especially in entering the second and the third lane, these tests showed a reduced steer angle, roll angle and vehicle slip angle. The vehicle slip angle is an appropriate indicator for the controllability of a vehicle.

Overall it was easier to successfully complete the test. This can also be quantified by an increase of the success rate from 30% to 80%.

Conclusions

It was shown, how the behaviour of a system containing of tractor and implement could be improved, using a mechatronic approach. The presented results indicate a significant potential of the approach. Advantageous with respect to possible market launch is the fact that standard tractors already have all the needed constructive parts. Thanks to the hydraulic lateral stabilizers there are already standard products for use as actuators available. It is assumed that this work could make an important contribution to improve the driving comfort and the driving safety of agricultural tractors. A patent for the method presented here has been applied [5].

Literature

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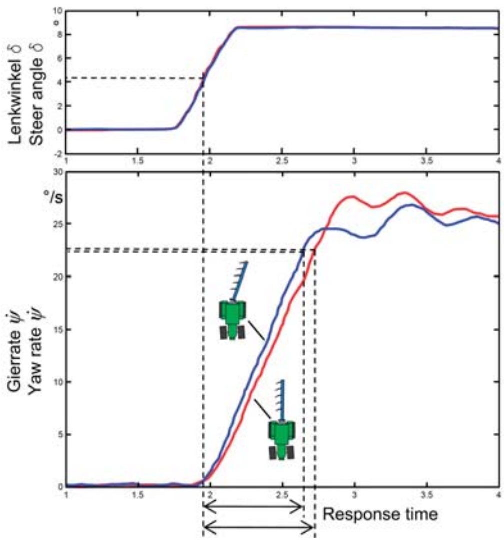
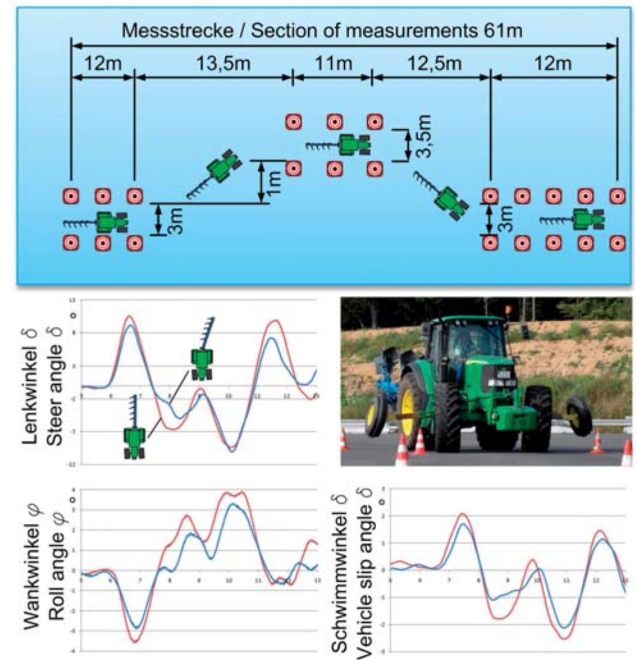
Fig. 4



Results of the steer step test according to DIN ISO 7401

Fig. 5



Test track and results of the double line change

Authors

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