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Pitch compensation by top cylinder

Due to increasing driving speed the target conflict between on- and off-road drive for agricultural chassis development grows. Alternative solutions for specific requirements reach their limits for ride safety and comfort on the one hand and soil protection and traction power on the other hand. Intelligent suspension systems with a passive or active controlled top cylinder could be a solution. The system allows a pitch oscillation compensation for driving on roads and traction assistance while working on the field.

Keywords
Tractor-trailer combination, driving safety, driving comfort, traction, simulation, hydro-pneumatic

Abstract
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Because of the steady increase of structural change in agriculture the distance between yard and field grows. The transport duration while driving on roads is a central cost factor and influences the efficiency of agricultural processes [1]. A realization of high driving speed and an optimized use of the potential load for tractor-trailer combinations are the key focus in modern chassis development. For field work, a high soil protection and a perfect traction are essential. High security requirements must furthermore be complied. The key objective of the subsidized research project by EFRE (Europaischer Fond für regionale Entwicklung) is a potential investigation of the so-called top cylinder as a replacement for the front weight. The focus of the study is to find evidence of functionality of the system. Component stress and admission conditions are excluded excluded from this examination. The research project is conducted at the Hochschule Osnabrück and was started in 2009 in cooperation with Fa. Kotte Landtechnik GmbH & Co. KG and Universität Hohenheim.

System description

Figure 1 shows the top cylinder installed above the tractor-trailer combination with rigid drawbar. A possible solution to replace the front weight by top cylinder is an active tensioning of tractor and trailer. When driving on the road without front weight, the minimum static axle load for security can be realized by top cylinder. In addition, pitch oscillations can be compensated by the insertion of drag forces as well as compressive forces. Off-Road the top cylinder can influence the axle loads of the tractor by compressive forces and control them depending on slip. Thus, an optimized traction of the all-wheel drive tractor even without front weight is guaranteed and a stalling can be prevented. The present article essentially deals with the pitch oscillation compensation.

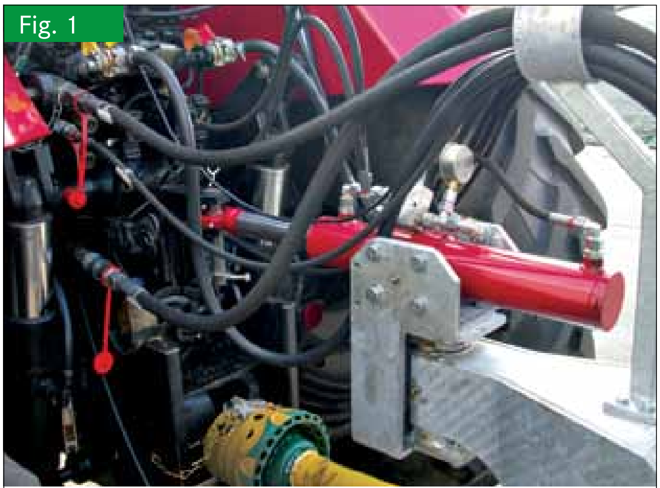
Vibration model

Driving safety and driving comfort stand at the forefront of attention for the replacement of the front weight by a top cylinder (see **Figure 1**). The assessment of these two special issues can be approached in two questions:

- Which dynamic axle load oscillation appears especially at the front axle of the tractor at high speed?
- Which accelerations experiences the driver at the suspended driver's seat?

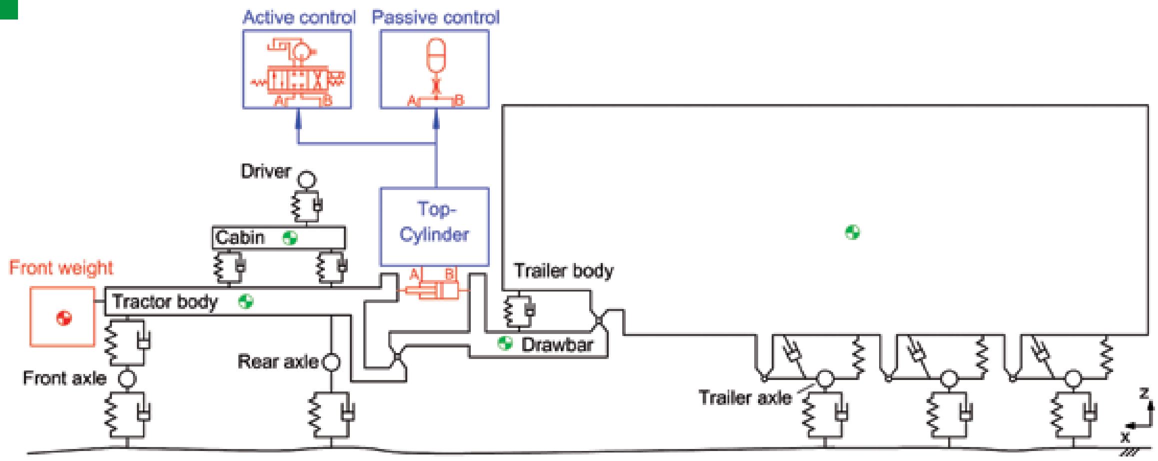
To answer these to questions a known mathematical vehicle model of a tractor with front axle suspension, cab suspension and driver's seat suspension [2] has been expanded by a trailer model with rigid drawbar in the form of a slurry tanker with drawbar suspension and axle suspension, which is shown in **Figure 2**. To describe the dynamic road behavior of the tractor tires, the Hohenheimer tire model is used [3] which has been

Fig. 1



Top cylinder installed above the connection between tractor and trailer

Fig. 2



Simplified, two-dimensional vibration model of a tractor-trailer combination with fixed drawbar and top cylinder

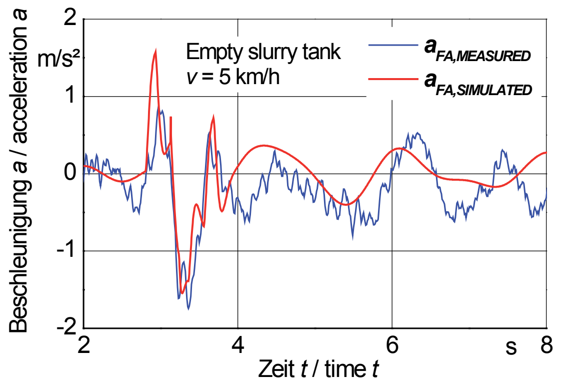
expanded by a so-called fixed footprint. In contrast to the one point excitation the fixed footprint considers the tread shuffle. Because of the symmetry to the longitudinal axis of the vehicle, the treatment of the lifting and pitching movement of the two dimensional linear model is sufficient. The parameterization has been done by fabricants disclosures, own measurements and estimations.

With this derived vibration model it is possible to examine different states of operation like payload, distance profile, velocity and their influence on driving security and comfort. The effect of the front weight can be tested, too. The simulation is carried out in Matlab/Simulink. **Figure 2** shows furthermore the two uses of the top cylinder. A passive one consists of a hydraulic throttle and the hydraulic accumulator, the active one of control by a 4/3-way control valve. Driving tests with obstacle and road excitation were done to validate the model. For those a prototype was used with which it is possible to measure the following values:

- Front axle acceleration (vertical)
- Tractor body acceleration (vertical and pitching)
- Driver's seat acceleration
- Vehicle velocity
- Top cylinder position
- Top cylinder pressure
- Drawbar pressure

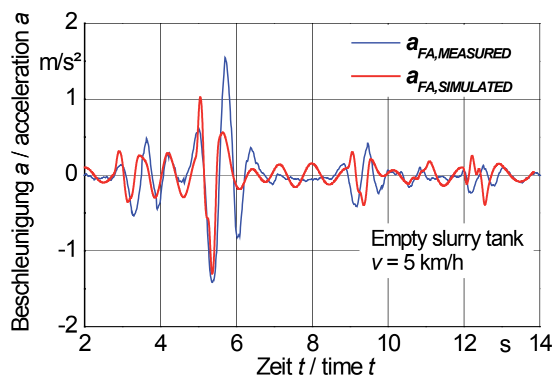
Simulated and measured results with front weight and a deactivated top cylinder while driving over an trapezium shaped obstacle for acceleration at the front axle and acceleration at the driver's seat are represented in **Figure 3** and **Figure 4**. After 2,9 seconds the tractor front axle passes over the obstacle and about two seconds later the rear axle follows, which is to be recognized at the driver's seat acceleration. The influence of the three trailer axles after 9 seconds is illustrated in **Figure 4**, too. Both results show a good quality agreement of simulated and measured accelerations. The frequencies are also similar in the area of excitation. The oscillation before and after the obstacle excitation especially at the front axle are traced back to the run out of the tires as well as to the road surface. Both parameters are part of the simulation and cause the phase displacement because of the stochastic road signal [2].

Fig. 3



Front axis acceleration while driving over an obstacle, measured and simulated

Fig. 4



Driver seat acceleration while driving over an obstacle, measured and simulated

Passive pitch oscillation

As an intermediate step for an active pitch oscillation control of the top cylinder, a passive has been conducted. The idea is a bracing of the tractor against the trailer to influence the oscillation behavior of the tractor body (**Figure 5**). This is realized through a hydraulic throttle as well as a hydraulic accumulator. A combination of both gives a spring-damping system. **Figure 5** on the left side shows the traditional assembly. The front weight is mounted and the top cylinder is deactivated (FMTD – Front weight mounted, top cylinder deactivated). On the Right side the front weight is not used and the top cylinder is activated (FDTA – Front weight dismounted, top cylinder activated). If only the degree of freedom of pitching is considered, the utilization of the top cylinder and the waiver of the front weight modify the Lehr's damping measure D of the tractor body pitching and a pitch compensation is the result (equation 1 and 2). The parameters of the equations can be found in **Figure 5**.

FMTD

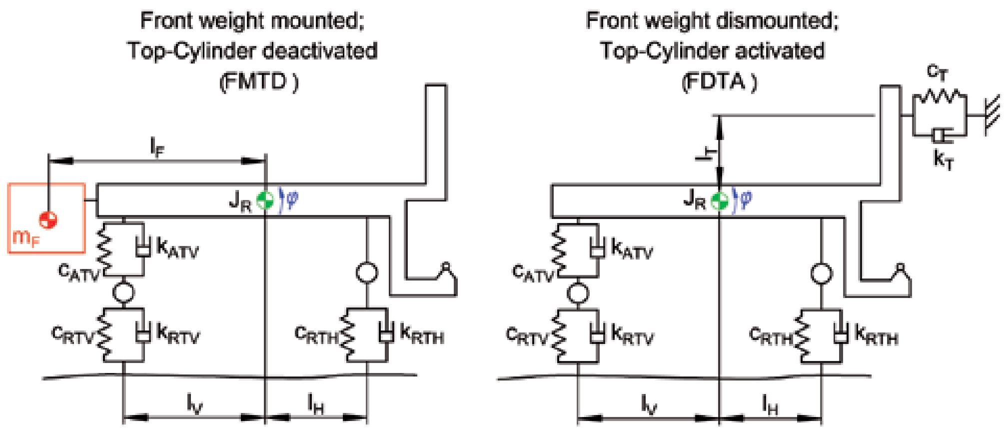
$$D_\varphi = \frac{k_{RTH} l_H{}^2 + k_{ATV} l_V{}^2}{2 \cdot \sqrt{(J_R + m_F l_F{}^2)(c_{RTH} l_H{}^2 + c_{ATV} l_V{}^2)}} \qquad \text{(Eq. 1)}$$

FDTA

$$D_\varphi = \frac{k_{RTH} l_H{}^2 + k_{ATV} l_V{}^2 + k_T l_T{}^2}{2 \cdot \sqrt{J_R (c_{RTH} l_H{}^2 + c_{ATV} l_V{}^2 + c_T l_T{}^2)}} \qquad \text{(Eq. 2)}$$

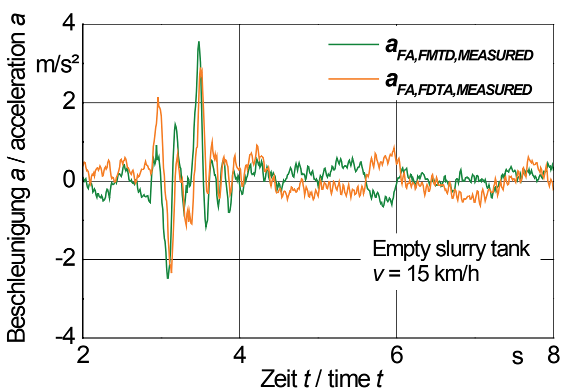
Based on the simulation model, the hydraulic throttle and the hydraulic accumulator were dimensioned and verified in driving tests. **Figure 6** and **Figure 7** show the front axle and driver seat acceleration while driving over the obstacle mentioned above. The top cylinder force is 15 kN. With this force, the static minimum load level at the front axle according to StVO is

Fig. 5



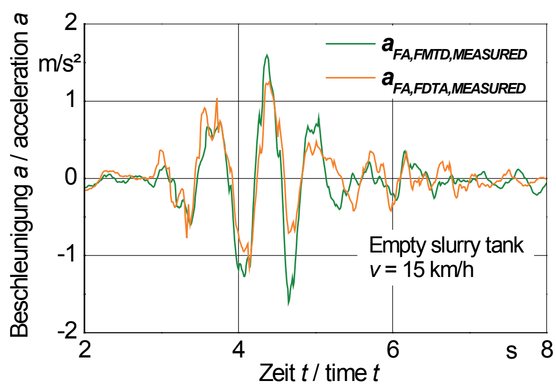
Passive control approach by top cylinder

Fig. 6



Front axis acceleration for passive control while driving over an obstacle

Fig. 7



Driver seat acceleration for passive control while driving over an obstacle generated and the Lehr's damping measure D is at least 7 % higher. The front axle acceleration with an activated top cylinder is stronger at first excitation than with front weight. Afterwards, both accelerations are similar. Because of the same acceleration process, one can conclude the result of same front axle load: the driving security remains. The driver seat acceleration is less strong with top cylinder which means more driving comfort. Measured accelerations while driving on the road are represented in **Figure 8** and **Figure 9.** For these values, the root mean square a_{RMS} has been calculated. Visible is a reduction through the application of the top cylinder by 5,4 % on the front axle and 15 % on the driver's seat.

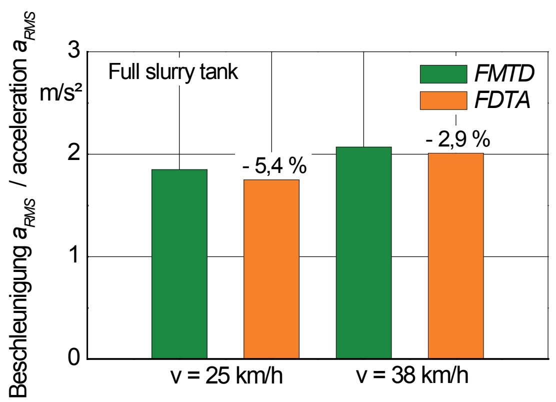
Conclusion

The results presented regarding passive pitch oscillation control while driving on the road show the positive influence on driving security and comfort of the top cylinder. Field tests for the traction assistance as the second target of the research project have been positive, too. The potential to replace the front weight exists even off road. This replacement would reduce the weight of the tractor-trailer combination by 500 to 1000 kg and this saved mass could be used to increase the payload. To follow critical aspects are still to be investigated:

- strengths,
- accreditation according to StVO,
- additional forces while turning maneuvers.

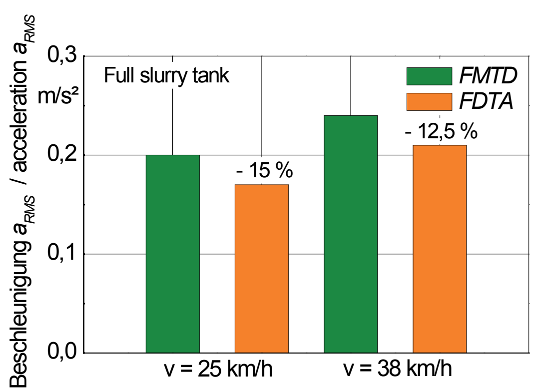
The next step of the research project is an active control of the top cylinder. While driving on the road, pitch oscillations should be reduced actively by a control of different state space variables like front axle acceleration, pitch acceleration and load pressure. The active control off road is planned as an influence of the axle road in dependence of tensile force, drawbar load and road inclination.

Fig. 8



Front axis acceleration for passive control while driving on the road

Fig. 9



Driver seat acceleration for passive control while driving on the road

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