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Modelling and simulation of tow angle between agricultural tractors and trailers

The tow angle between tractors and trailers of agricultural transport vehicle combinations is an important parameter if vehicle-train stability is concerned. This angle is affected by both tractor and trailer behavior, thus unexpected movement of any of them can be recognized in unexpected change in tow angle. This makes the tow angle be an excellent parameter of vehicle-train lateral stability determination. In order to determine difference between expected and measured tow angles a measuring and a calculating method has to be developed.

Keywords
Vehicle-train stability, agricultural transport systems, pull-angle

Abstract
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The subject of this paper is the stability analysis of transport vehicle combinations consisting of agricultural tractors and propelled axle trailers, and the reduction of accidents related to the trailer drive. Special attention has been paid to the accidents caused by the pullrod–force, which are usually result of increased trailer pushing force, incorrect braking balance, heavy soil conditions. A computer model of a transport vehicle park has been developed, which capable of performing dynamical simulations of transport vehicle trains and which can be the basis for developing stability control theories. In order to determine the stability of the vehicle combination, the current and the expected value of a carefully chosen key-parameter must be known, which stability determining parameter in this case is the pull-angle. In this paper a method of calculating the expected value of the pull-angle, a measuring instrument and a stability determination method will be introduced.

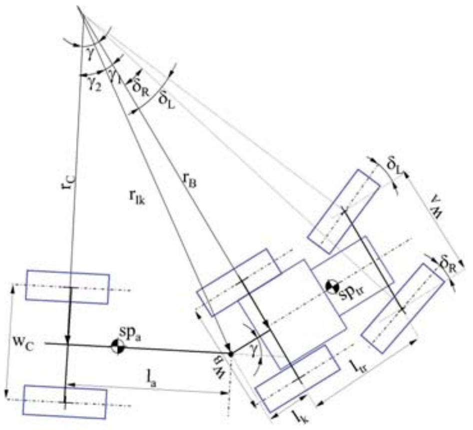
Materials and Methods

Determination of the Pulling Angle

Pulling angle: (Also towing angle [1]) The horizontal component of the angle between the pulling and the pulled vehicle. The pull-angle is zero, when the trailer is in-line with the tractor. Notation: γ (° or rad)

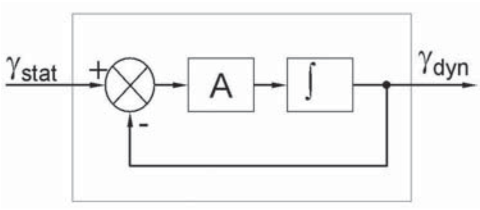
One method of determining the state of the vehicle is based on measuring the pulling angle and comparing its value to the expected one. To determine the expected value of the pulling angle, I have introduced the extended Ackermann conditions of steered wheel angles to vehicle trains. **Figure 1** shows a tractor and a trailer attached to it. The angles of the steered wheels (δ_L, δ_R) are calculated in the conventional manner of Ackermann's method [2].

Fig. 1



The extended Ackermann-condition of vehicle trains

Fig. 2



Model used for the determination of actual pull-angle

The Ackermann condition of vehicle train is fulfilled when not only the axles of the wheels of the tractor but also the wheels of the trailers are pointing in the theoretical turning center (momentan centrum). The γ_{stat} pull-angle in the steady curving can then be calculated using the notations of **figure 1** as follows:

$$\gamma_{stat} = \gamma_1 + \gamma_2 \qquad \text{(Eq. 1)}$$

where

$$\gamma_1 = \arctan\left(\frac{l_k}{r_B}\right) \qquad \text{(Eq. 2)}$$

and

$$\gamma_2 = \arcsin\left(\frac{l_a}{r_{lk}}\right) = \arcsin\left(\frac{l_a}{\sqrt{(l_k^2 + r_B^2)}}\right) \qquad \text{(Eq. 3)}$$

Equation (2) und (3) substituted in equation (1):

$$\gamma_{stat} = \arctan\left(\frac{l_k}{r_B}\right) + \arcsin\left(\frac{l_a}{\sqrt{(l_k^2 + r_B^2)}}\right) \qquad \text{(Eq. 4)}$$

The turning radius of the rear axle is:

$$r_B = \frac{l_{tr}}{\tan(\delta_L)} + \frac{w_A}{2} \qquad \text{(Eq. 5)}$$

The calculated steady state γ_{stat} pulling angle is equivalent only in steady curving with the actual pulling angle.

The reason for this is that in contrast to the δ_L, δ_R steering angles of the front-left and front-right wheels of the tractor, which immediately occur as the steering wheel is turned, the pulling angle is continuously changing as the vehicle moves. To reach its steady state value, the vehicle has to travel a certain distance.

My goal was to set up a model or equation, which describes the actual value of the pulling angle, not only in steady- but also in transient state.

Figure 2 shows the block scheme realisation of the transient state pull-angle determination. The variable A is reciprocal of the time constant of the T1-type system. In equation

$$A = \frac{v_x^{tr}}{l_a + l_k} \quad \left(\frac{1}{s}\right) \qquad \text{(Eq. 6)}$$

where v^{tr}_x is the speed of the tractor (in m/s), $l_a + l_k$ is the distance of the axles of the tractor and the trailer (in meters).

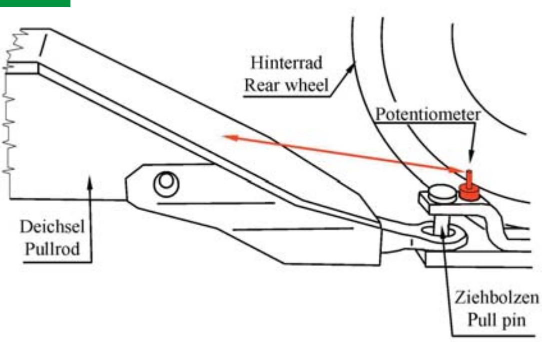
The actual value of the pulling angle in a differential equation form

$$\frac{1}{A}\frac{d\gamma_{din}}{dt} + \gamma_{din} = \gamma_{stat} \qquad \text{(Eq. 7)}$$

Measuring the pull-angle

The advantage of the chosen vehicle-stability determination method is the simple measuring of the pull-angle. The sensor can be easily mounted posteriorly on the already existing vehicles. **Figure 3** shows the mounting location of the angle measuring

Fig. 3



Measuring the tow angle

Fig. 4

Device for measuring the tow angle

device, **figure 4** shows the measuring device itself, which is a telescopic rod, a ball-head on one end, and a joint on the other. This rod equalizes all motion between tractor and trailer, but the tow angle, which is transmitted to a potentiometer, which transfers the angular motion into voltage signal.

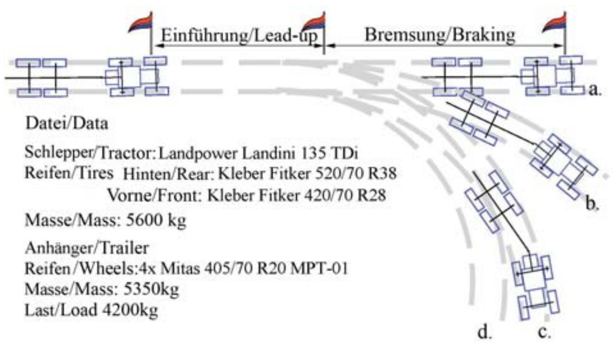
Validations by Field Measuring

Combined Braking and Steering Test

I have done the validations using a vehicle combination consisting of a Hungarian made SR-10 type (manufacturer: „Mezögépfejlesztö Ipari Rt“) propelled axle forwarder attached to a Landini Landpower agricultural tractor 135TDI.

The measurements were performed on the lands of the forest of Kisalföldi ErdÖgazdaság Rt. at the Ravazdi Erdészet location. The measuring track is shown in the **figure 5.** The steady-state stage is 30 meters long, and the braking stage is also 30 meters. The steering angles are from a to d 0, 7, 15, and 28 degrees (measured on the front left wheel).

Fig. 5



Plan and data of the combined braking and steering test

The measurements were performed on a dry sunny day, with temperatures in the range of 20-23 ^{0}C. The soil was a brown forest soil, permanently maintained, grass covered clearing.

During the taking of the measurement, data were partially manually and partially electronically recorded. The measuring sets became a code for further pairing of the corresponding manually and instrumentally recorded data.

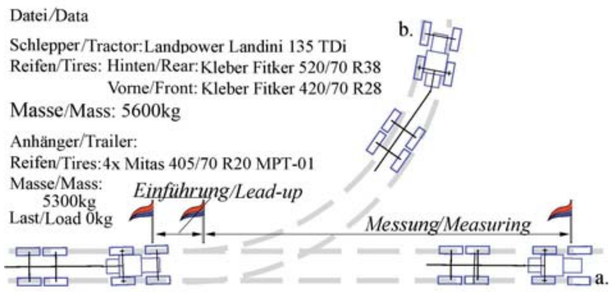
Roundabout Test

One of the stability programs is based on measuring the pulling angle between the tractor and the trailer. The roundabout test is to validate the determination of the expected value of the towing angle in steady and transient states. The first stage is a lead up, while the second stage is a roundabout at the maximum steering angle of the tractor.
In this test only the trailer drive was applied.

The Barn-Test

The barn test were performed in an empty barn, which was under construction. The barn had fine sand and a level bedding, which appeared ideal and easily reproducible. In the bedding I marked a short stage to achieve a near steady-state running of the vehicle combination, followed in case “a” by a 20-meter-long straight track, and in case “b” a left turning (**figure 6**).

Fig. 6



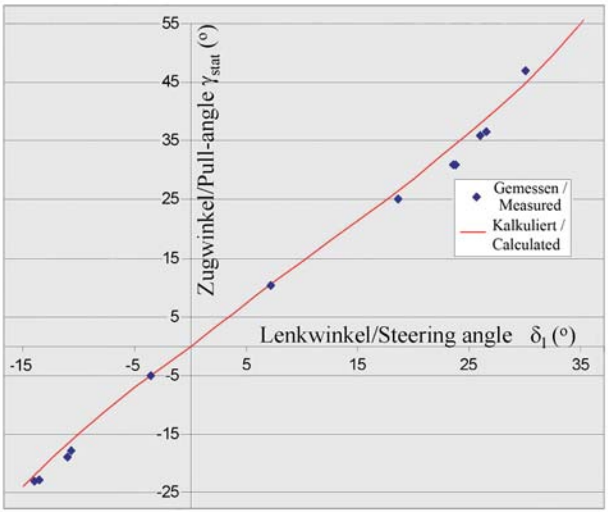
Plan and data of the barn test

Results

Steady state towing angle calculation

Figure 7 shows the comparison of the calculated and the measured steady-state pulling angles. The continuous line shows the function of **equation 4**, and the squares are the date gained from the field measuring. This result validates the determination of the steady-state pull-angle determination. Coefficient of determination: R^2=0,98

Fig. 7

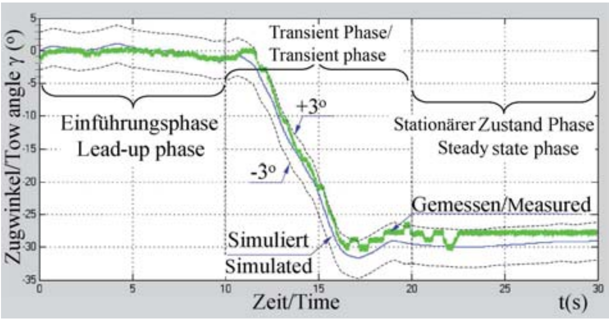


Comparison of measured and calculated tow angles

Transient state towing angle calculation

From the recorded measurement data, the steering and pull angle data have been taken. I have created a computer model of the vehicle train and set the parameters in accordance with the measured vehicle. Using the recorded speed and steering data, I have reproduced the simulation with the model. The pull angle produced by the simulation then was compared with the measured one (**figure 8**). The figure has been divided into 3 parts, namely lead up, transient and steady-state. A ±3 degrees tolerance band around the simulated tow angle has been drawn, which corresponds 3 degrees absolute tolerance at zero degrees, and 10 % relative tolerance at 30 degrees of tow angle. It can be seen that the measured tow angle remained within the tolerance band. The model used for determining the transient state of the tow angle gives satisfactory result, therefore it can be used as the parameter of vehicle stability determination.

Fig. 8



Comparison of measured and simulated tow angles over 3 phases

Conclusions

The pulling angle determination model was validated by a series of field measurements. The expected pulling angle can be compared with the measured one, and from the deviation the stability of the vehicle train can be determined. The advantage of this method is that the pull angle deviation can be caused both by the pulling vehicle and the trailer; in this way abnormal behaviour of either of them can be determined.

Literature

Books are signed with ●

[1] Towing definitions on the ProPride Inc. home page. http://www.propride-hitch.com/trailer_sway/towing_definitions.html, Zugriff am 02.01.2010
[2] ● Mitschke, M.: Dynamik der Kraftfahrzeuge. Band C, Springer Verlag, Berlin, 1990

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