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Automated Deceleration of Agricultural Tractors

Agricultural transport combinations weigh up to 40 t and travel at speeds of up to 60 (or even 80) km/h. If these combinations are decelerated by lowering engine revolutions and or increasing the transmission ratio, especially when driving downhill, engine rpm's may get too high. On some occasions, the driving wheel slip may get too high, thus lowering the driving stability. Especially with tractors with power-split CVT's, which have gained a noticeable market share recently, the potential of these risks is high. The goal of this research project is to develop strategies for automatically operating the vehicle's service brakes in critical driving situations, in order to increase traffic safety and prevent damage to the engine and transmission.

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The Project "Traktorbremsmanagement" is promoted by the Deutsche Forschungsgemeinschaft.

Keywords

Tractors, driving safety, deceleration management

In Germany agricultural tractors are often used for transports. Typical agricultural transport combinations consist of a tractor weighing about 6-8 t and two trailers of significantly higher weights. These combinations weigh up to 40 t and travel at speeds up to 60 km/h. If such a combination is driving downhill and the driver tries to decelerate it by lowering the set value of the engine speed and/or increasing the transmission ratio without using the service brakes, two problems are likely to occur. Firstly, there is the danger of the diesel engine rpm getting too high, and secondly, the driving stability can be affected. Since the whole combination is decelerated via the tractor's driving axle, and the trailers, which are considerably heavier than the tractor, are not braked, the slip of the tractor's driving wheels may rise significantly which could lead to a jackknifing of the combination (*Fig. 1*).

The use of the tractor's service brakes avoids both problems because the engine load sinks, and furthermore, the slip of the driving wheels is lowered by braking all axles of the combination.

Today's agricultural tractors are often equipped with partial powershift transmissions. With these transmissions the above-named risks are limited, because as soon as the driver shifts to a lower range he has to use the brakes to be able to engage a lower gear. However, this does not apply to tractors with CVTs, which have gained a noticeable market share recently. With these CVT's the transmission ratio can be changed very efficiently without any traction interruptions by simply operating the control lever or pedal. Thus, the above-named risks are raised substantially because high braking forces can be generated without using the service brakes.

The tractor manufacturers have taken measures to avoid these situations. Possible strategies are, e.g., preventing the transmission ratio from rising while driving downhill, or lowering the transmission ratio when the diesel engine overspeeds. They both have the purpose of forcing the driver to use the service brakes when driving downhill. However, it would be more secure and more comfortable to operate the service brakes automatically in these situations.

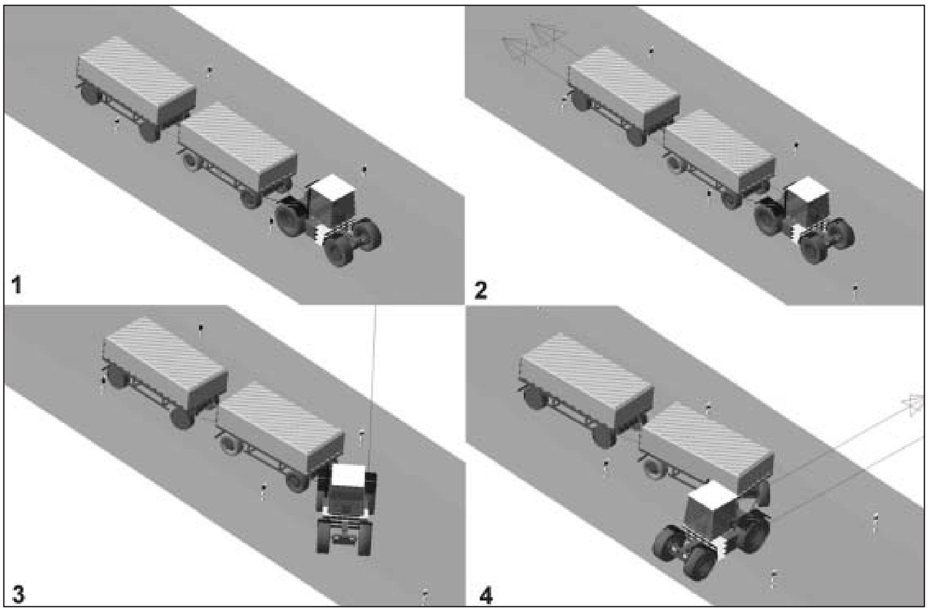


Bild 1: Einknicken eines landwirtschaftlichen Transportzugs

Fig. 1: Jack-knifing of a tractor-trailer combination

Project objectives and approach

To achieve this, the Institute of Agricultural Machinery and Fluid Power at the TU Braunschweig is carrying out a research project which is funded by the Deutsche Forschungsgemeinschaft (DFG). The main objective of the project is to develop the fundamentals of the automated braking of agricultural tractors equipped with CVT's during the driving situations described above.

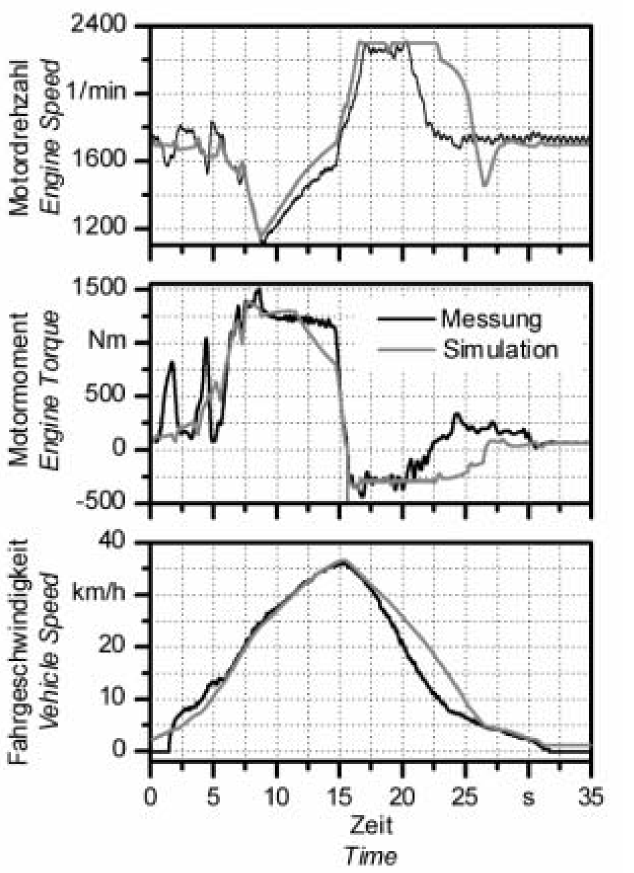
The first goal is to find parameters which are suitable for the detection of critical operating situations. If possible, these parameters should be limited to those which are already being measured and utilised for control purposes in today's tractors. The use of an extensive range of additional sensors, e.g. those being used in modern cars and trucks for vehicle dynamics control systems, is not intended. Following this, control strategies for the automated operation of the service brakes will be developed.

The investigations are carried out by using a stationary test rig as well as a numeric simulation of the system tractor-trailer-road.

The simulation model has been built by using the software Matlab/Simulink and represents an agricultural tractor coupled with two trailers. The model calculates the behaviour of the diesel engine, the transmission, and the forces and torques that emerge in a driving tractor-trailer combination, including the traction forces between tyres and road surface. The model is 2-dimensional, thus the lateral vehicle behaviour is not included. *Figure 2* shows a comparison of the simulation model with a measurement of a real tractor-trailer combination. The combination was accelerated from 0 to 35 km/h and afterwards decelerated until it stopped. During the test, the set value of the engine speed was held constant, only the transmission ratio was changed. The diagram shows the engine speed, the engine torque and the vehicle's driving speed. During the acceleration the behaviour of the simulation model matches that of the real system very accurately. During the deceleration process some divergences occur, which are mainly caused by the fact that the drag torque characteristic of the real tractor's diesel engine was unknown and had to be estimated. The limitation of the engine speed to 2300 1/min during the deceleration process is caused by one of the above-mentioned measures to protect the diesel engine against overspeeding. If the engine speed exceeds 2300 1/min the transmission ratio is held constant until the engine speed falls below the critical value.

The test rig used for the investigations contains a diesel engine, a hydrostatic-mechanical powersplit CVT, and an electronically operated disc brake at the transmission's output. For the calculation of the loads that occur in a driving tractor, the simulation model (without diesel engine and transmission) is coupled with the test rig. The loads are calculated on-line by analysing the operating behaviour of the diesel engine and the CVT, and are applied to the CVT's output by a hydraulic system. Since the hydraulic power that can be applied is limited, only selected driving situations can be simulated at the test stand. Thus, for the bigger part of the investigations the simulation is used, as it can reproduce arbitrary driving situations.

Fig. 2: Comparing field test and simulation



Identification of critical operating conditions

The critical operating condition occurring most frequently is the overspeeding of the diesel engine. The detection of this condition is quite easy, because it only requires the analysis of the engine's speed signal. Thus, an overspeeding can be detected early and prevented by automatically operating the service brakes.

The detection of a lowered driving stability of the combination, caused by a high slip ratio at the tractor's driving wheels, is more difficult. One possible indicator is the deceleration produced by braking via diesel engine and transmission, which can be calculated quite easily by analysing the rates of change of engine speed and transmission ratio. Another approach would be to estimate the braking forces at the driving wheels. If the drag torque characteristic and the efficiency characteristic of the transmission are known, the braking forces can be calculated by analysing the engine speed and the transmission ratio. However, the disadvantage of these solutions is the fact that the service brakes have to be operated at relatively low decelerations or loads respectively, because the actual traction coefficient between tyre and road surface cannot be taken into account, and therefore a low traction coefficient has to be assumed for safety reasons.

A more appropriate approach could be the calculation of the actual slip ratio by using a radar sensor to measure the real driving speed. These sensors are installed in many modern agricultural tractors. The slip ratio itself as well as its rate of change could be used to detect critical situations.

Future prospects

The next step of the project is to develop a way to detect critical driving situations based on the approaches described above. Subsequently, control strategies for the automatic operation of the tractor's service brakes will be developed.