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Loads in the traction drive of a self-propelled forage harvester

For self-propelled agricultural machines the required continuously variable traction drive is nowadays mainly based on hydraulic components. Published researches according to the load spectra of those drivelines do not cover the rapid machine development of the last years. Therefore, the complementary load spectra of the traction drive of a self-propelled forage harvester were measured, illustrated in three different aggregation levels and interpreted. The established data represent typical in-field conditions including different groundspeeds, modes of header guidance and driving, as well as on-road operations.

Keywords
Load spectra, forage harvester, hydrostatic traction drive

Abstract
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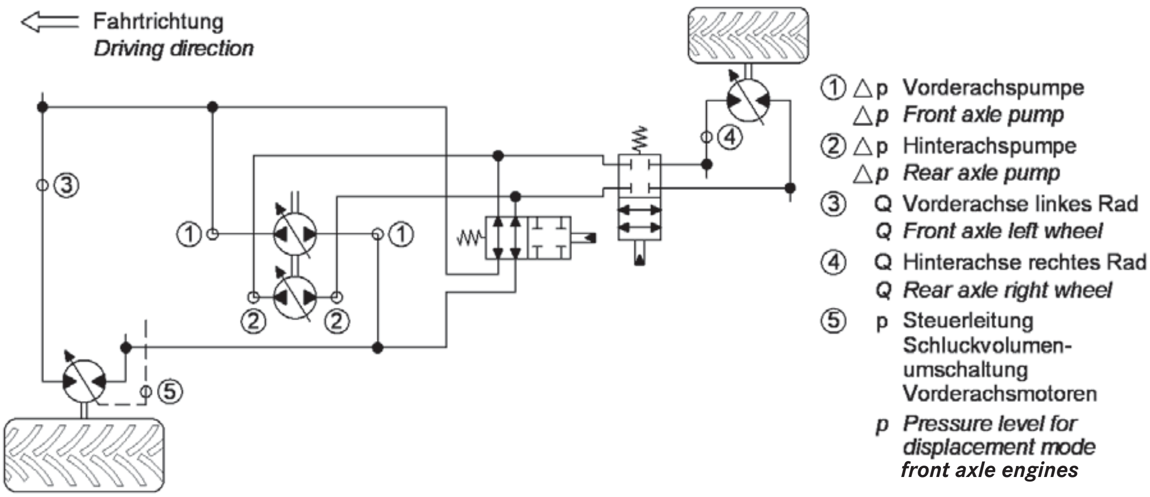
Self-propelled forage harvesters get more and more important in crop collection processes. The state of the art in this field is for example engine power up to 750 kW, maximum transport velocity of 40 km/h combined with a maximum working width of 10.5 m. The engine power splits up into the single drivelines, with the biggest fraction of about 70 % for the crop cutting and conditioning process and about 10 % for the traction drive [1]. The load part required for the traction drive is alternating due to machine usage and setting. If these alternative loads are logged under typical working conditions, they can be presented in load spectra. For self-propelled harvesting machines like combines or forage harvesters load spectra of the traction drive are already published [2; 3]. But these do not correspond with the latest state of the art regarding range and design of transmissions or the gross weight of the machines.

Materials and methods

In the forage harvest 2007 load collectives were logged in the hydrostatic traction drive of a self-propelled forage harvester KRONE BiG X 1000. As torque and speed could not be measured directly, the hydrostatic parameters pressure and flow rate were logged with a frequency of 33 Hz [4]. Due to the available measurement equipment of the Agricultural Systems Engineering Lab of Technische Universitaet Muenchen (TUM) data logging was only possible at one wheel of each axle. For the investigation the left front axle wheel and the right rear axle wheel were selected to be analysed. **Figure 1** shows the schematic overview of the system, which is based on two pumps, and the single measurement points [5].

For in-field testings the forage harvester operated near the research station Hirschau of TUM in 2007. The harvest and soil conditions on even ground were excellent. The test runs can be classified into in-field operations, on-road operations and special testings, e.g. for simulating loading the harvester on a

Fig. 1



Measurement assembly for load spectra in the hydrostatic traction drive of a self-propelled forage harvester

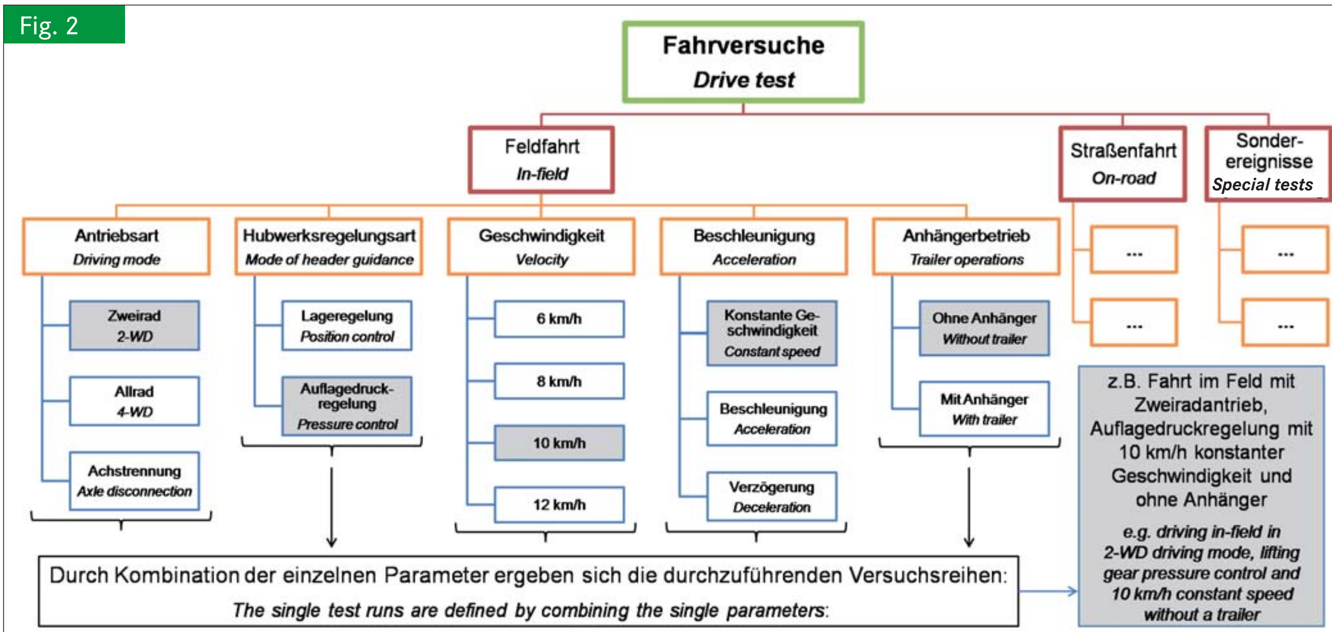
truck (**figure 2**). All in all 119 different test runs with several repetitions were realized, resulting from combining the single test parameters [6]. Later on the herein collected data were aggregated in three different levels.

Every single test trail was illustrated in time response with the measured variables torque and power. The runs with constant speed were used to generate a comparison of different machine settings. Therefore varieties of machine parameters were compared by plotting against velocity. Only test-groups, which differ in one parameter were checked against each other. Thereby the impact of different machine settings on power and torque requirements of the traction drive can be detected and quantified. All collected data were used to generate load spectra for in-field and on-road operations and for the two driving modes 2-WD and 4-WD.

Results

In **figure 3** a single test run during in-field operations on even ground is exemplarily shown. Herein the torque and power requirements of the two examined wheels as well as the velocity in time response are drawn. In the raw data some of the pressure variation is caused by the system. To reduce the system influence a moving mean is calculated using six raw data values. In the test machine all four radial piston engines are parallel switched. This fact causes an almost equal pressure in the whole systems. That's why the torque relation approximates the displacement relation of the examined hydrostatic engines. Caused by a lower rolling circumference a higher output speed is necessary at the rear tires for equal speed. Hence the power ratio between front and rear axle is lower than the torque ratio. The significant fluctuation at the beginning of the test run

Fig. 2



Exemplary compilation of one single test trial out of the varied machine settings

Fig. 3

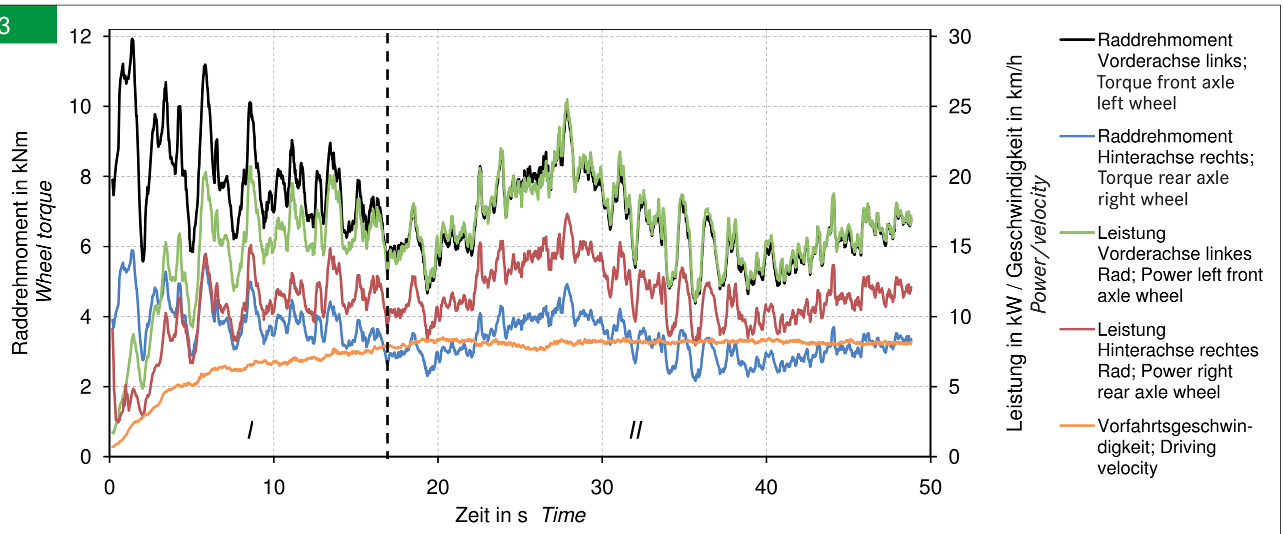
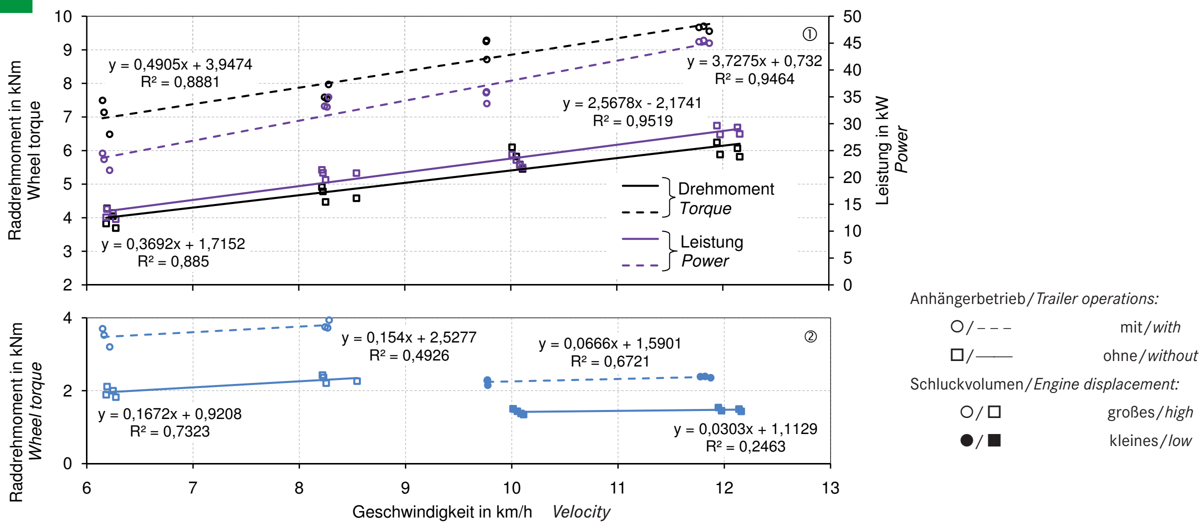


Illustration of torque, power and velocity for a test trial during harvesting operations, engaged 4-WD drive, header lifting gear pressure control, without trailer

shows the driving to the mainland over the machine tracks on the headland (*I*) while speeding up to 8 km/h. Driving with a constant speed of 8 km/h in the mainland (*II*) the maximum power measured for the left front axle wheel is about 25 kW and for the right rear axle wheel about 17 kW. If it is assumed, that the oil flow is divided equally to both engines of an axle, the calculated power requirement of the whole traction drive is about 84 kW at this point. This value represents the power provided by the hydraulic pumps. Losses in the transformation of energy in the engine power take-off-gear and in the pumps are not included.

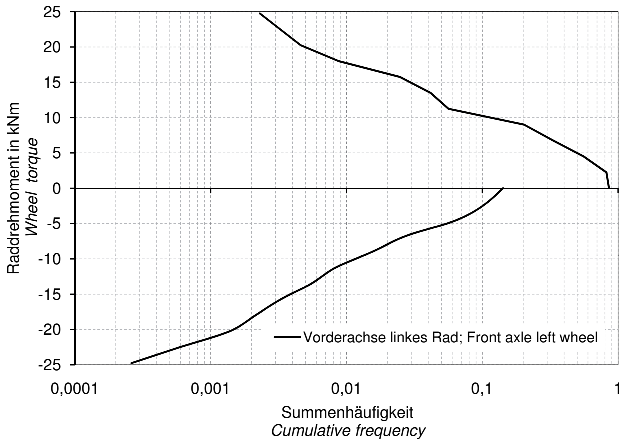
To determine the impact of trailer operations while harvesting, test runs with and without trailer under otherwise same conditions are compared with each other (**figure 4**). For the torque of the left front wheel and the power of both wheels it can be figured out, that slopes of the regression lines are higher for trailer operations. Speed increase from 6 to 12 km/h causes an increase in torque of about 50 % for the left front wheel and in power of both wheels of about 37 %. Through trailer operation with a trailer mass of 10 160 kg the torque requirements of the left front wheel increase in-between 60 % and 75 %. For the power requirements of the traction drive the trailer causes

Fig. 4



Wheel torque (Front axle left wheel in ① and rear axle right wheel in ②) and power (Cumulated front axle left wheel and rear axle right wheel in ①) depending on velocity for test trials under in-field conditions with 4-WD driving mode comparing trailer operations (trailer mass 10 160 kg) with non-trailer operations on flat surface

Fig. 5



Load spectra of the traction drive of the forage harvester during on-road operations for varying road conditions and slopes

a similar relative increase. The regression lines for the torque of the right rear wheel are interrupted because of the displacement shift in the radial piston engines. Thereby the contribution to the whole driving force in the high speed range is lower.

For classifying the logged data on a larger scale, the measurements are aggregated into different load spectra. For that reason, the data have to be separated into 2-WD and 4-WD driving mode [7]. Out of all measured data the torque values are drawn with their specific cumulative frequency, as shown in **figure 5** for 2-WD operations. Positive wheel torque up to 10 kNm occurs for the left front wheel in 75 % of all cases. Higher positive torque values are logged for 10 % of all data. Negative wheel torque results out of hydraulically caused retarding or driving backwards and occurs for 15 % of all measurements. The negative torque can also be split by 10 kNm. 93 % of all negative data is lower than 10 kNm, 7 % are respectively higher. This is caused by the excess width of the machine, especially if oncoming traffic occurs, the harvester is often forced to slow down, particularly on narrow roads.

Conclusions

The comparative classification of load spectra on basis of the limited number of available publications is quite difficult, especially in view of the technological progress of the last years, which was already described in the beginning. Comparing the results of this project with a paper about load spectra in tractors is not suggestive because of the different traction drive requirements. But the examined machine parameter can be ranked with reference to their relative influence on the traction drive during driving with constant speed:

- Trailer operations
- Velocity
- Mode of header guidance
- Mode of driving

The single machine parameters have a direct influence on the power and torque requirements of the traction drive. Hence it is now possible to evaluate the machine settings and their influence on the traction drive. Further the results can be used for optimizing, advancing and developing drivelines in similar machines.

Literature

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