Measuring and interpreting load spectra in the hydrostatic traction drive of a self-propelled forage harvester

Determining loads and load differences caused by various modes of driving

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Abstract

For self-propelled agricultural machines the required continuously variable traction drive is nowadays mainly based on hydraulic components. Existing publications according to the load spectra of those drivelines do not cover the rapid machine development of the last years. Therefore, the complementary load spectra at the traction drive of a Krone self propelled forage harvester (SPFH) was measured, illustrated in three different levels of aggregation 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.

Introduction

Continuously variable traction drives in self propelled harvesting machines were introduced in the 1950´s in Germany. This innovation was driven by the advantage of increased productivity based on stepless speed adoptability associated with a constant drive speed of the modules. For these traction drives load cycles for self propelled harvesting machines were measured for combines in 1965 [1]. The data were logged on a 75-kW-class combine, whose driving force was converted by a three gear mechanical transmission in combination with a continuously variable module. For hydrostatic traction drives the pressures in the hydraulic circuit of combines and SPFHs were measured by WENDORFF (1995) [2]. Additional to the mechanical part of the transmission, a hydrostatic unit was used in combination for stepless speed variability in the investigated machines. But these publications cannot cover the rapid machine development within the last years, e.g. the increased top speed for SPFHs of 40 km/h or the wide spread need for two powered axles, especially if harvesting in wet or hilly regions. Also there are no investigations related to direct hydrostatic traction drives without any mechanical transmission, which are used in the KRONE self propelled machinery. Therefore, new load spectra for self propelled SPFHs have to be investigated under consignment of the changed machine characteristics within the last years. But due to the available measurement equipment of the Agricultural Systems Engineering Lab of the TUM data logging on one wheel of each axle was only possible.

Assembly of measurement equipment and test lead

For the investigation the left front axle wheel and the right rear axle wheel were selected to be analysed. As torque and speed could not be measured directly, the load spectra the hydrostatic parameters pressure and flow rate were logged with a frequency of 33 Hz. The hydrostatic system of the traction drive is described in detail by HINSCH [3]. Figure 1 shows the schematic overview of the system and the single measurement points. The pressures on both sides of the two pump circuits were logged for the calculation of the pressure differences. In combination with the flow rate in each circuit, the power and torque requirements of the traction drive could be generated related to various driving modes [4]. A DGPS receiver was added to complete the georeferenced data logging system.

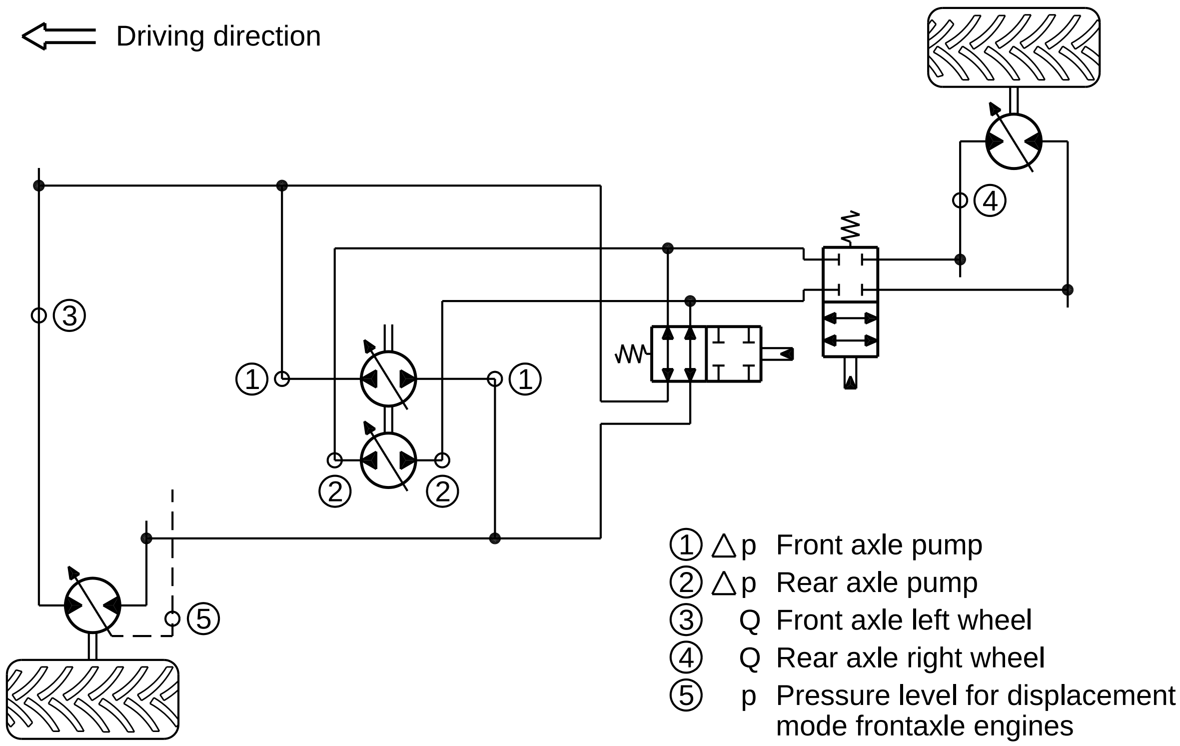

Fig. 1: Measurement assembly for load spectra in the traction drive of a forage harvester

The investigation was done under in-field and on-road operation under typical conditions [5]. Machine settings were:

- Mode of driving (2-WD, 4-WD, 4-WD with axle-disconnection),
- mode of header guidance (lifting gear pressure control, lifting gear position control),
- speed over ground between 6 and 12 km/h,
- acceleration and deceleration,
- operations with or without trailer.

The test results were enhanced for three different levels of aggregation. 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 are compared by plotting against velocity. Only test-groups are checked against each other, which differ in one parameter. 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 modes of driving 2-WD and 4-WD.

Results of field tests

Based on the investigations, power and torque for each monitored wheel is plotted depending on time. For overall 119 different machine settings the data are logged in several repetitions. One of the test-runs is exemplarily shown in Figure 2 for driving in flat terrain. Section I describes driving with constant speed of 6 km/h, in section II the SPFH speeds up to 12 km/h and section III represents constant driving speed at 12 km/h. The peak in power looking at both wheels is about 105 kW. In the middle of section II the radial piston engines of the rear axle shift their displacement from a high to a low one and therefore the wheel torque in section III is obviously lower than in section I.

To determine the impact of trailer operations while harvesting, test runs with and without trailer under otherwise same conditions are compared. For starting harvesting in the fields, the FH sometimes pulls the trailer by itself or, if harvesting under wet soil conditions, the FH has to pull out stocked machinery. To simulate these operations, the FH additionally pulled a trailer while working. The results of the comparison are drawn in Figure 3. The upper chart contains the wheel torque of the left front axle wheel (drawn in black and referring to the primary y-axis) and the power of both monitored wheels (drawn in grey and referring to the secondary y-axis). Trailer and non-trailer operations are to differ by dashed and continuous lines. The lower chart describes the torque of the right rear axle wheel for the high and low engine displacement. All parameters are plotted depending on velocity.

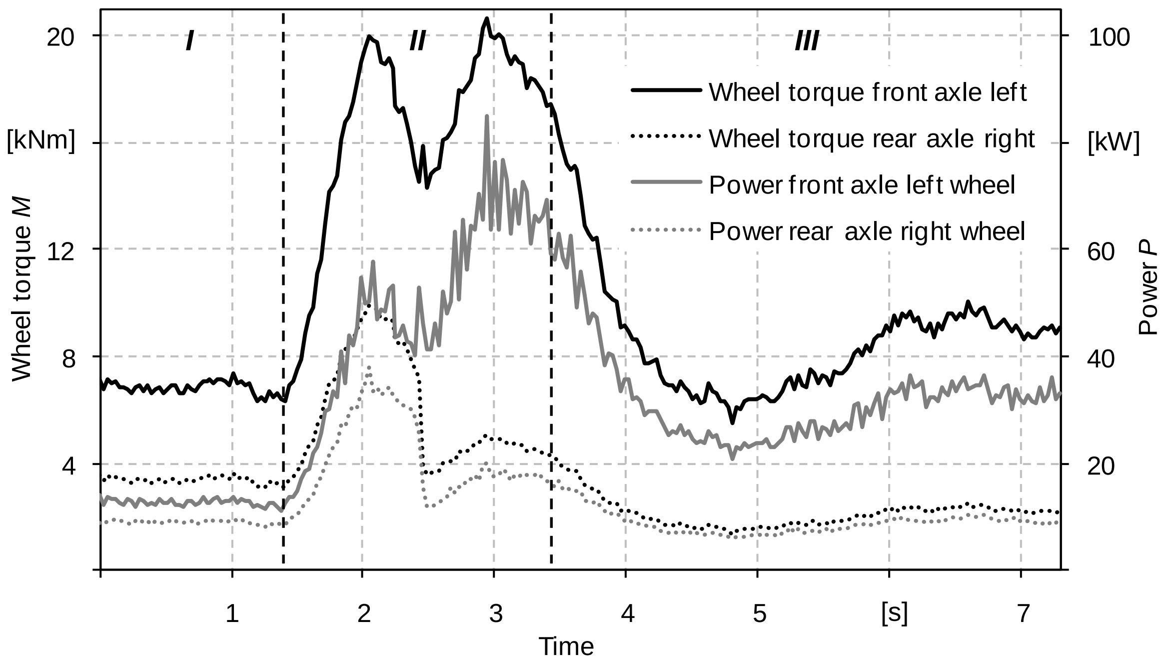

Fig. 2: Torque and power of left front and right rear wheel under in-field conditions in 4-WD mode with a trailer-mass of 10.16 Mg during an acceleration from 6 to 12 km/h

Thereby the impact of the additional trailer mass on the torque and power requirements of the traction drive depending on velocity can be detected. For the front wheel torque and the power of both wheels can be figured out, that slopes of the regression lines are higher for trailer operations. Regression lines for the rear wheel torque are interrupted because of displacement-shift of the engines between 8 and 10 km/h. In low engine displacement the contribution of the rear axle to the whole driving force is relatively low. With equal pressure in the front and the rear axle circuits it approximates the displacement ratio of the engines and the differing wheel radius'. The trailer mass is about half of the SPFH mass. Through trailer operation between 6 and 12 km/h the torque requirements of the left front wheel increases in-between 60 % and 75 %. For the power requirements of the traction drive the trailer causes a similar relative increase. The absolut values for power shown in the graphs do not reflect the power supplied by the combustion engine. Specific losses in the engine power-take-off-gear, in the hydrostatic pumps and for the charge pump are not included in the illustrated values. This has to be considered when talking about the power requirements for traction drive at the combustion engine. If it is assumed that the oil flow is devided equal to both engines of one axle, traction force and power of the hole traction drive can be calculated.

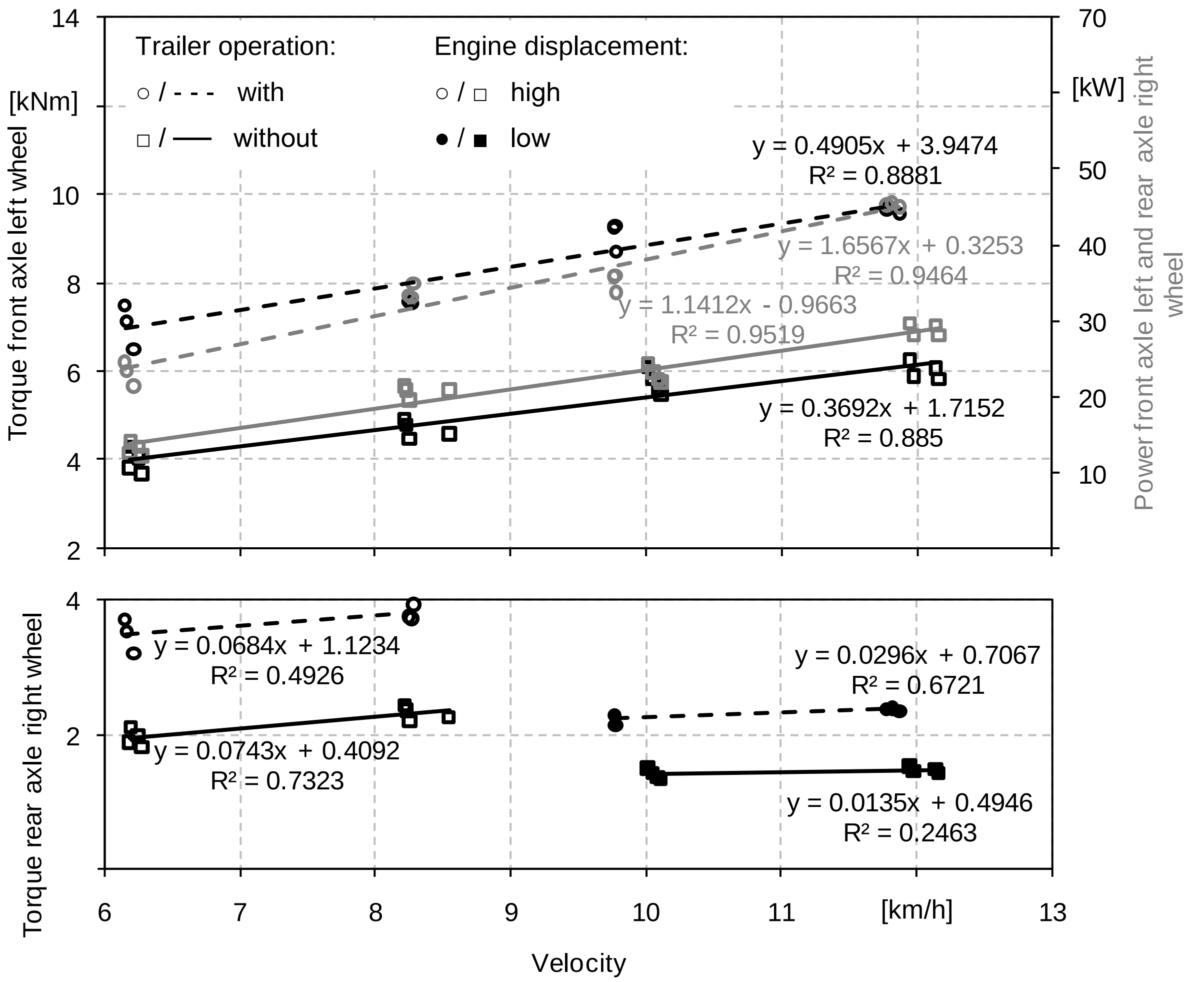

Fig. 3: Wheel torque (in black) and power (in grey) depending on velocity for test trials under in-field conditions with 4-WD mode comparing trailer operation (trailer mass 10.16 Mg) with non-trailer operation

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. Figure 4 shows the 4-WD driving mode during in field operations on almost completely flat surface and under very well harvesting and soil conditions. For 16 % of all cases, the torque of the left front wheel is higher than 8.5 kNm. For 83 % the loads are in a range between 0 and 8.5 kNm. Negative wheel torque with less than 1 % cumulative frequency results because retarding is not prevalent. One reason therefore is the relatively high roll resistance of the machine in the field. Similar results were monitored for the rear axle wheel with correspondingly lower torques. The reason for the 97 %-rate of all measurements lying in between 0 and 6 kNm is the fact, that above 9 km/h the rear axle engines are working in low displacement with respectively lower torque.

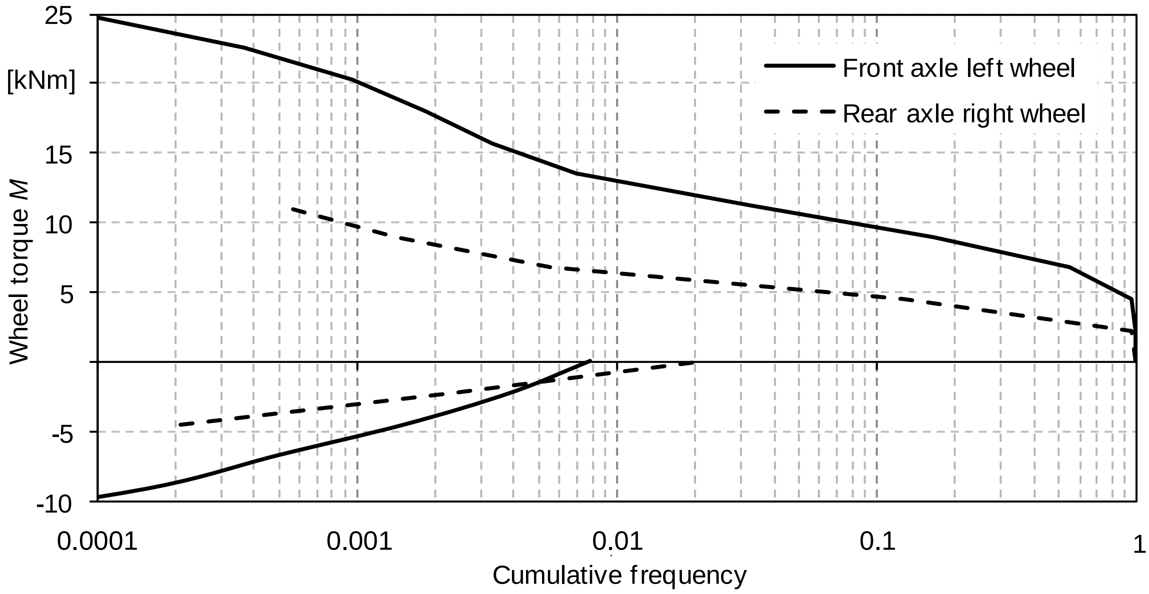

Fig. 4: Load spectra of the test machine for in-field operations in 4-WD driving mode

Conclusion

The information of the loads on the traction drive can be used to improve the actual driveline as well as to develop a partly or completely new traction drive. Regarding the second issue, the work will be continued to develop an electrically driven rear axle based on the collected data. A final comparison between both drivelines is aspired to complete the overall project.

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