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Experimental Comparison of Ground Drives for Combine Harvesters

Since the mid eighties, hydrostatic ground drives have become common for larger harvesting machines. But, due to the continuous development of electric drive systems during recent years, these have also become interesting for self-propelled agricultural machinery. The DFG financed a research project in 2003 and 2004 at the University of Hohenheim for comparative testing of hydrostatic and electric ground drive systems, to acquire quantitative data and serve as a basis for evaluation.

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Dedicated to Prof. Dr. Ing. Dr. h.c. H. D. Kutzbach on occasion of his 65th anniversary.

Keywords
Combine harvester, electric ground drive, ground drive

Fig 1: Hohenheim test combine

The efficiency and performance of drive systems, especially of ground drive systems, are recently discussed among agricultural engineers. In the automotive sector electric drives shaped as parallel hybrid drive systems have already reached the level of series production. In the meantime, prototypes of electrically driven tractors and self-propelled harvesting machines have appeared which could prove the suitability of mobile electric drives for agricultural uses. Since a comparison of ground drives only makes sense at equal conditions, the Hohenheim test combine was equipped with two parallel drive systems.

The Hohenheim test combine

On the one hand the test combine can be driven by an electronically controlled hydrostatic drive, consisting of a variable displacement pump, a control unit and a variable displacement motor. On the other hand an electric power transmission was build up, consisting of a synchronous generator, two inverter modules and an asynchronous motor. All electric components are water-cooled. The power input from the diesel engine to the drive train and the power output to the central gear of the drive axle is implemented at the identical shafts for both power converters. Thus, the losses which do not depend on the system and transmission ratios from the engine to torque converter and from the torque converter to the wheels are identical (*Fig. 2*). To compare the subjective drivability both torque converters are controlled by the same control lever in the cabin.

Test-results

The results of the field-tests under normal working conditions of the combine harvester show comparable efficiencies for both drive trains during the harvesting process. A dependence on the viscosity of the hydraulic oil η_D and the voltage of the electric DC in-

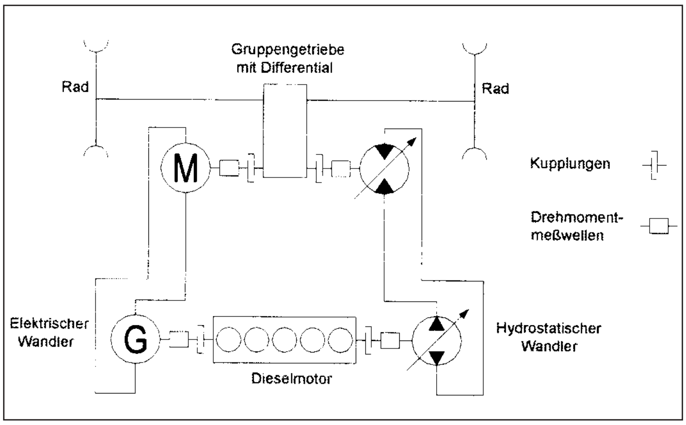

Fig 2: Schematic set up of the parallel ground drives

termediate circuit U_{ZK} was obvious [4]. During the on-road tests the electric drive had some advantages (*Fig. 3*), which can be explained by the low load of the hydrostatic converter at maximum oil flow. This effect cannot be reduced without an additional gear. The efficiency of the electrical drive increases with increasing rotational speed. Nevertheless, this advantage is of little importance due to the low rate of driving on-road.

To generate a defined load to the drive trains, drawbar-pull tests were performed. The combine pulled a braking tractor with a tow bar and a force measurement frame mounted to the tractor, as described in [5]. Caused by the high load of the drive trains, efficiency-values between 0.55 and 0.80 resulted at little advantages for the electrical drive. The maximum of the transferable power was lower for the electrical drive (*Fig. 3*), caused by the inverter modules, whose maximum current is limited to I_{max}=200 A. Even at a magnetization-current of I_M=150 A current-peaks can cause a turn-off of the drive. Thus, only the nominal torque of the electric motor M_N=240 Nm could be reached.

Basing on the totality of the measured values, efficiency-maps in dependence on the output-rotational speed and the output rotational torque were generated for the electric and the hydrostatic torque converter (*Fig. 4*). The curves for the upper torque limit are based on the maximum transmittable power. Each point of the figure shows the mean result of a complete test. As the torque of the electric motor is limited (240 Nm), high speeds were needed to transmit high power. In contrast, the hydrostatic converter could transmit the whole engine power even at low speeds. For the hydrostatic converter the maximum drawbar pull is limited by the mass of the combine at low speeds, at higher speed the engine power is the limiting factor.

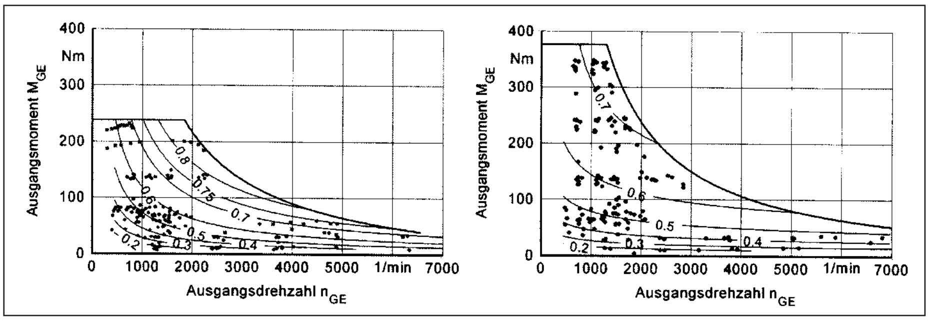

Fig 4: Ground drive operating maps of the electric torque converter at U_{ZK}=650V (left) and hydraulic torque converter (right) regarding torque and rotational speed

The regression-maps of the efficiency in both figures are calculated by the equation

$$\eta = a_1 + a_2 \cdot \ln(n_{GE}) + a_3 \cdot \ln(M_{GE}) + a_4 \cdot M_{GE}$$

The electric converter did not show a linear dependence between output torque and efficiency, in this case the parameter a_4 becomes zero. These maps clearly show the equal efficiency-values for both torque converters under normal working conditions at low torque-values and an output speed between 1000 and 2000 rpm. Outside of this range the electric converter shows little advantages at the efficiency, the hydrostatic converter can transmit the higher maximum power, especially at low speed.

Subjective driveability

The adjustment of the driving speed was similar for both drive trains. The control speed had to be limited for acceleration and deceleration of both converters to avoid acceleration values, which endanger the stability of the vehicle. The maxima of the acceleration are as high as wanted for both systems, so they are of little value for a comparison of the different drive trains. The controllers were parameterised to achieve a comfortable and save driving

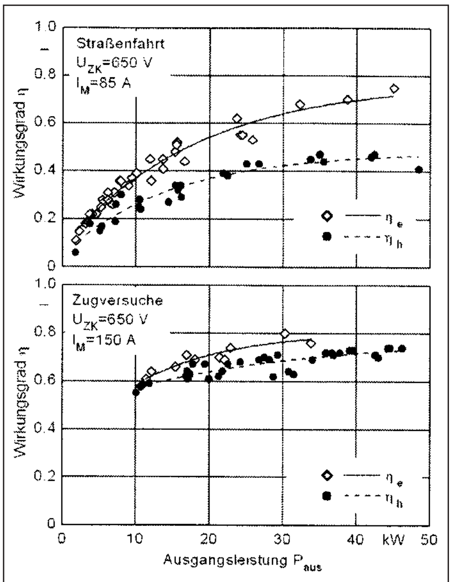

Fig 3: Drive train efficiency η depending on the power output of the torque converter Paus during on-road and traction tests

Conclusions and Outlook

As a result of the two inverter modules, needed for the electric drive train, the complexity of the control and the required space for the components is higher as for the hydrostatic drive train. However, the electric drive affords enhanced control- and adjustment-opportunities. For example the speed zero can be realised exactly with the electric converter, while this is impossible with a hydrostatic converter, due to internal leaking oil losses. Access to the diesel engine control for automotive driving as much as a speed control basing on engine speed or engine torque are realisable within both drive trains. Both converters have an adjustable speed range which is big enough to cover the relevant speeds of self-propelled harvesting machines between 0 and 30 km/h.

The power to weight ratio of the electrical components was improved during the last years. Anyhow, the mass of the components of the electric drive train is six times higher than the mass of the hydrostatic components. But compared to the total mass of the combine harvester, this additional mass is almost negligible since it has only a portion of 3 %.

Additionally, the needed installation of a water cooling system for the electric components has negative effects, because it has to be installed beneath the power supply line. The hydrostatic converter uses the same oil for the power transmission as for the cooling of the system.

In contrast to the hydrostatic drive train, which is a closed circuit system because of the turning of rotational direction and turning of torque direction, the electric converter can be enhanced by additional electric motors. The opportunity to make electric power available for small auxiliary-consumers arouse the interest of the manufacturers of agricultural machines.

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