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Alternative Module Drives for Mobile Working Machines

With increasing fuel prices consumer demands for optimized use of operating inputs grows stronger. A direct approach is to increase the efficiency factors of power trains. Based on positive experiences, electric drives have found increasing application in stationary drives [1]. For mobile agricultural application it is necessary to consider different, much more diversified application spectra, and the suitability of an electric drive must be assessed with other criteria.

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Keywords

Power train, electric drives, efficiency factors

Literature

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In cooperation with Maschinenfabrik Bernard Krone GmbH a project was initiated to assess new electric and the typical hydraulic module drives on their applicability as distributed speed-variable module drives. Therefore one of the most important criteria is the efficiency in power transmission. Compared to the industrial application especially the dynamically varying working point, caused by varying load or speed, has to be recognized. Hence parallel to the efficiency assessment at stationary working points, research work considering typically dynamic load is necessary.

The objective within the project is to assess two comparable systems and prove the suitability of the electric prototype during field tests.

Prototype electric drive system

As basis the two modules header and intake of a self propelled forage harvester are replaced by electric drives. For dimensioning typical loads, data of the hydraulic module drive were collected during the harvesting period 2005. Figure 1 shows an overview of the resulting diesel-electric prototype drive system. Therein designs as well as control are integrated in the existing machine concept. The variable axial piston pumps of both hydraulic circuits are replaced by a common permanently excited synchronous generator, which power via a diode rectifier bridge the intermediate direct current link with variable voltage.

At the motor side reluctance drives with integrated inverter within the terminal box are used. For powering the intake module, the hydraulic motor is directly replaced by an electric one. But the previously centrally installed hydraulic header drive is changed into two electric drives, which are installed in the header itself. Thereby the mechanical driveline consisting of gearboxes and shaft drives is unnecessary for powering the header. The common interface, where the electric system replaces the hydraulic one, is the chain drive gearing. The generator and the motor and as also the rectifier and inverters are liquid cooled, to increase the power-to-weight ratio and to ensure cooling also under dusty field conditions. Integration into the vehicles cooling circuit has not been realized, because of the lower temperature level, which is required. Therefore an additional cooling circuit must be installed with an own electric coolant pump and cooler. To operate the speed of the drives at first the current for pump control is used to calculate a speed level. Afterwards this is adapted to the variable chopping cylinder speed, using the Diesel engine speed as reference. This is necessary to clone the hydraulic behaviour also in the electric drive. Therein the flow rate varies if the input speed changes at constant displacement and adapts thereby the modules speed automatically to the also varying chopping cylinder speed.

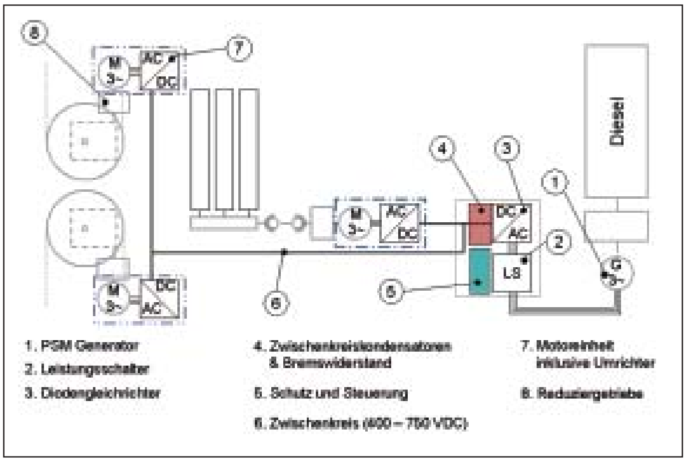

Fig. 1: Electric power train for the modules intake and header

Method for assessing powertrains

A major aspect in the future will be the efficient use of energy resources. The assessment of the efficiency is therefore a very important criterion. Hence reproducible test

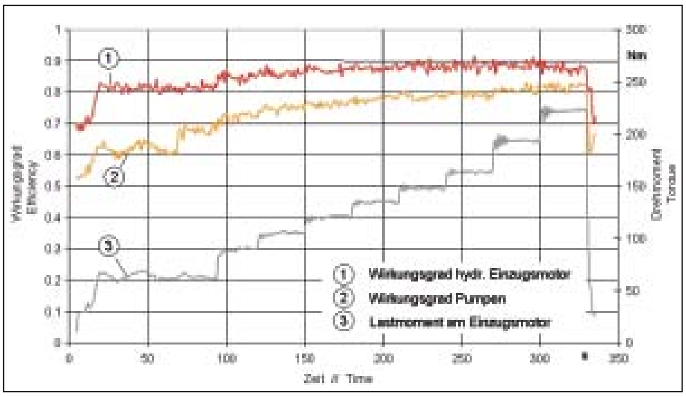

Fig. 2: Efficiency factor ratios of the hydraulic intake drive and of the pumps at different load levels

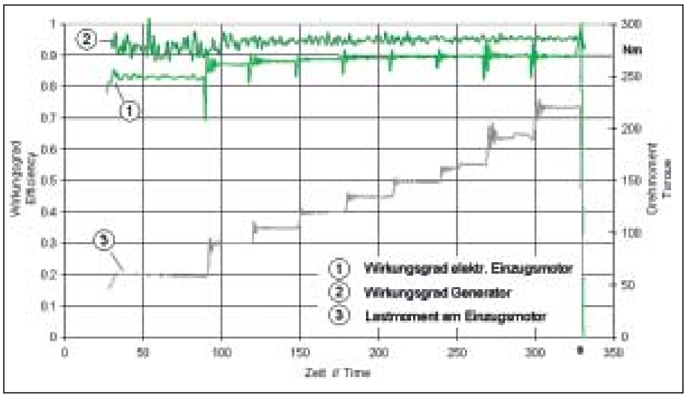

Fig. 3: Efficiency factor ratios of the electric intake drive and of the generator at different load levels

stand work at the DLG Test Centre in Groß-Umstadt is basis for assessing efficiency and therewith the exploitation of primary energy. Thereby the DLG-PowerMix drawbar vehicle [2] is used as controllable load for header and intake. The header drive including all mechanical transmission elements is therefore linked to the PTO break of the drawbar vehicle via a summation gearing. Because only one mechanical link is available, the intake drive is loaded by a hydraulic pump system, which works at the hydraulic test ports of the vehicle.

In stationary tests the behaviour at load levels between 10 and 140% of nominal torque was examined regarding different cutting length of 6, 8 and 10 mm. Also variable Diesel engine rpm are necessary to be considered. On the one hand, different speeds in the hydraulic powertrain adapt automatically module speed by changing the flow rate, on the other hand different speeds cause a variable dc link voltage in the electric system. This results in different nominal currents, even for the same load at the modules and therewith the operating parameters change fundamental. Variations of Diesel engines speed are hence examined between 1500 and 1850 rpm with increments of 50 rpm.

For the hydraulic powertrain as well as for the electric counterpiece the measurement of the transmission efficiency is based on logging the mechanical power input and the mechanical power output by torque flanges at the pump/generator, intake and header. For detailing efficiency and losses at the hydraulic driveline, additionally the conversed hydraulic power is logged by pressure gradient, flow rate and oil temperature. During the measurement both modules are loaded parallel at the drawbar vehicle with load cycles. Thereby pumps and generator are also stressed typically. To get comparable information for the electric powertrain, the behaviour of generator, intake motor and the total system is tested with a 4 channel power analyser at the electric side. Because only a 4 channel power analyser was available, it was necessary to divide that test into three different runs with different measurement setups. To rate the cooling system the run-back temperatures of all drives and the generator, the inflow and escape temperature of the cooler and at the temperature of the electric coil of the generator and intake motor are logged.

Efficiency factors compared

Looking at the single units considerable differences occur between motors and generator/pumps. At the motors side the efficiency of energy conversion is nearly the same. The hydraulic one is working with a hydraulic-mechanic efficiency factor between 89.8% and 87.2% under full load conditions for different Diesel engine speeds and a cutting length of 8 mm. It decreases during partial load conditions of 30% of nominal torque to 81%. Figure 2 depicts the time dependent torque and the corresponding efficiency of the hydraulic intake drive and pumps during different load levels with a cutting length of 8 mm and a diesel engine speed of 1750 rpm.

The electric intake drive ranges between 88.1% and 90.6% during full load operation and decreases to 80.7% during partial load (basic conditions: cutting length: 8 mm; diesel engine speeds: 1500 to 1850 rpm). Considerable enhancement of the electric system results from the substantially more efficient electric power supply. At full load operation, the generator including the rectifier enables about 95%. The efficiency of the hydraulic pumps instead is between 78.2% and 82.5%. Figure 3 depicts the time dependent torque and efficiency at intake drive and generator of the electric driveline during the same conditions like in *Figure 2*. Noticeable is especially the constant high efficiency, also during partial load. The hydraulic pumps show a much more distinctive dependency to load.

This results in an efficiency factor of less than 70% during full load operation for the total hydraulic driveline. In the electric one instead an efficiency of about 85% is realised. This is caused on the one hand by the more efficient energy conversion at the generator but also by less mechanical transmission parts at the header drive.

Installation size and power-to-weight ratio

In contrast to the advantageous efficiency the power-to-weight ratio of the electric drives is disadvantageous. Related to the modal working point the hydraulic intake drive has a ratio of 1 kg/kW. The electric one has instead a ratio of 5.9 kg/kW. At the side of the power supply, differences are lower. Here the hydraulic pumps weigh 121 kg at a glance, the generator 160 kg, both offering the same effective power. The situation for the installation size is the same. The used electric intake drive needs six times more installation size as the hydraulic one.

Conclusion

The results point out considerably advantageous efficiency factors for the electric driveline, compared to a closed circuit hydraulic one, of about 15%. Even more differentiated is the situation, if the electric one is compared to open circuit hydraulic systems. Critical is the significant increased power-to-weight ratio of the electric drives. But it is necessary to note that in this project drives were chosen from original stationary applications, because of their availability. Power-to-weight ratios between 1.25 to 1.5 kW/kg are already realized in optimized mobile applications [3]. Permanently excited synchronous motors with external rotor used as hub motor feature even a power-to-weight ratio of less than 1 kg/kW [4]. In addition to the stationary operating performance the dynamic one is important, which occur at both modules. Therefore typical load levels, load gradients and interdependencies between the modules were extracted from field test data. Based on these, a test cycle was calculated using a modified Monte-Carlo Method [5]. These cycles are used to control the drawbar vehicle to stress the modules what enables to assess the dynamic performance.