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ALTERNATIVE MODULE DRIVES FOR MOBILE WORKING MACHINES

MICHAEL GALLMEIER[1]; HERMANN AUERNHAMMER[2]

[1] Researcher, Chair of Agricultural Systems Engineering/TU Munich – Germany. e-mail: michael.gallmeier@wzw.tum.de
[2] Prof. i.R., Chair of Agricultural Systems Engineering/TU Munich – Germany. e-mail: hermann.auernhammer@wzw.tum.de

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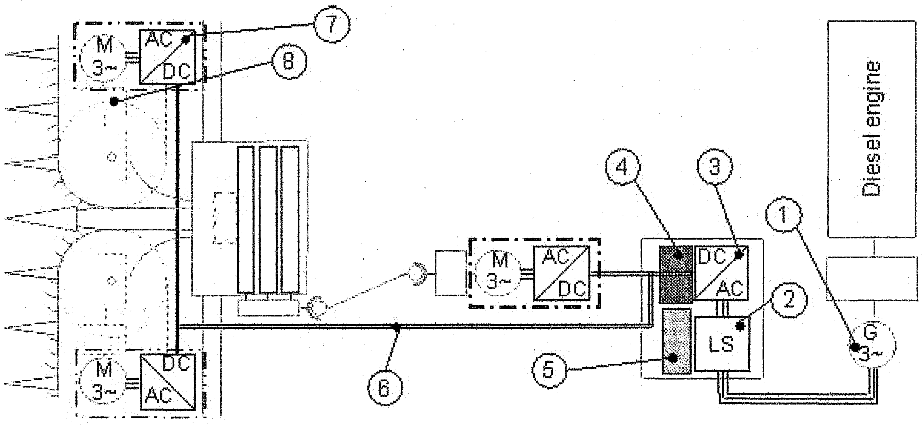
ABSTRACT: Due to the increasing fuel costs the demand of users on optimized usage of resources is raising. A direct approach is given by the increase of powertrain efficiency. An alternative pointed out by stationary industrial solutions are electrical drive systems. These gain in importance because of very positive experiences in efficiency and controllability during the last years. But for the mobile agricultural application it is necessary to consider different, much wider application spectra. Hence the applicability of electric drive trains must be assessed mentioning different criteria. Therefore a project was started in 2005 in cooperation with KRONE and funded by the Deutsche Bundesstiftung Umwelt (DBU). In the project the electric drive enables energy efficiency enhancements between 14 to 20% considering the typical dynamic load cycles of a forage harvester. Disadvantageous are the higher weight and the larger size of the electric components compared with the standard hydraulic solution.
KEYWORDS: Power train, electric drives, efficiency factors

INTRODUCTION: For further enhancement of machines capability speed variability for dynamic adaptation of the modules to the actual environmental parameter is an important key in future. Therefore today often hydraulic drivelines are used to power modules and power split gearings for traction drives. Advantageous are thereby size and weight of the drive units, disadvantageous are their efficiency factors and the risk of environmental pollutions by oil leakage.
For this speed variable applications in stationary industrial applications more and more electric drivelines with frequency converters establishes because of higher energy efficiency, better controllability and their easy integration into networks. Thereby operating costs can be reduced directly.
But the requirements in the mobile agricultural use are different and aspects like power-to-weight ratio and installation size have to be mentioned next to energy efficiency, too.
Therefore a project was started in September 2005 in cooperation with "Maschinenfabrik Bernard KRONE GmbH" and funded by the "Deutsche Bundesstiftung Umwelt DBU" to compare hydraulic and electric powertrains. Exemplary the hydraulic drives for header and intake system of a self propelled forage harvester were chosen, which represent about 11% of the power demand of the total machine.

METHODOLOGY: The objective within the project is to quantify the differences in energy efficiency of standard hydraulic drivelines and an electric prototype and their weight and size. For assessing energy efficiency a test stand setup was configured which enables reproducible load at both drivelines and stresses the whole driveline.
At first stationary operating conditions were examined. Therein different load levels between 10 and 130 % of nominal torque are considered at different diesel engine speeds between 1500 and 1850 rpm and different cutting length between 8 and 10 mm.
To validate these information for the typically dynamic application on the other hand dynamic load cycles are used to compare energy consumption behavior. Therefore typical load cycles were

calculated based on load data acquired in field tests in 2005. These load cycles represent the typical load, the load gradients and the interdependencies between header and intake. The statistic approach for calculating these representative test cycles out of field test data is described in (GALLMEIER & AUERNHAMMER, 2006).
The test stand work is based on the drawbar vehicle of the DLG test center in Groß-Umstadt (Germany) which provides a mechanical and a hydraulic interface to load header and intake drive dynamically. During the tests driveline efficiency is always calculated from the measured torque and speed at the motor gearbox and the header and intake module. Additionally the conversion efficiency of pumps, generator and drives were calculated based on hydraulic or electric power measurements for each unit. Therefore the pressure gradient and the flow rate were logged for each module in the hydraulic setup and voltage and current before and after the converter at the electric one.
To prove suitability of the electric driveline under typical conditions in field tests about 100 ha of maize were harvested.

Electric driveline for intake and header
Both hydraulic pumps working in different closed circuits for separate powering of intake and header are replaced for the electric prototype system by a single permanently excited generator. In addition with an uncontrolled diode rectifier a DC voltage link is powered. Because of the permanently excited generator and the uncontrolled rectifier the dc link voltage depends on the speed level of the diesel engine and varies between 780 and 400 VDC. For the electric prototype the hydraulic intake drive is directly replaced by an electric one. This enables the comparison of two single drives. To power the header two electric motors are mounted directly with an additional planetary gearing at the two sprocket wheel gearings. Therewith the centrally mounted hydraulic drive and the mechanical driveline consisting of several shafts and gearings can be replaced. For both modules reluctance drives are used with integrated inverters for connection to the DC link. Drives control is realized via a BUS and an additional signal calculated from the control current of the hydraulic pumps as general speed reference. Figure 2 depicts schematically the electric driveline. To improve the power-to-weight ratio and ensure cooling also during dusty field conditions generator, drives, rectifier and inverters are liquid cooled. At the prototype an additional cooling circuit is necessary because of a lower coolant temperature level.



1. Generator
2. Power switch
3. Rectifier
4. DC link capacitors and brake resistor
5. Safety and control
6. DC link (400 – 750 VDC)
7. Drive unit with inverter
8. Planetary gear

FIGURE 1. Prototype of an electric driveline powering intake and header in a self propelled forage harvester (depicted without cooling system)

RESULTS AND DISCUSSION:
The realized stationary examinations cover all typical working conditions between 30% and 140% relative load for a cutting length between 6 mm to 10 mm and varying diesel engine speeds between

1500 rpm and 1800 rpm. Figure 3 depicts the advantage in the conversion efficiency of the electric driveline compared to the hydraulic one regarding different load levels and diesel engine speeds for a cutting length of 8 mm. During these stationary tests the electric driveline enables to increase the efficiency of power transmission between motor gearbox and module about 14 percentage points to 30 percentage points. This advantage is manly caused by the more efficient electric power supply. Generator and rectifier enable an efficiency factor near to 95% during full load operation whereas the hydraulic pumps are limited at about 80%. The hydraulic and electric module drives achieved comparable performance.

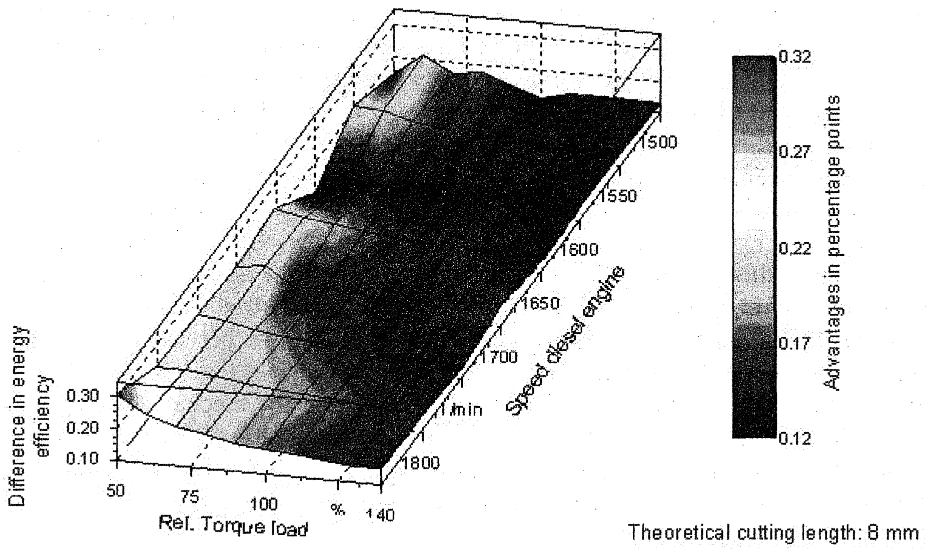


FIGURE 2. Stationary efficiency of hydraulic and electric module drives depending on the load level

The energy efficiency behavior of both drivelines during machine and process typical dynamic load cycles is depicted in figure 4. Here power transmission efficiency is calculated from the mechanical power input and output during the cycle. Shown are utilized capacities between 60% and 130% nominal load (1, 2) at a diesel engine speed of 1750 rpm and a cutting length of 8 mm and the efficiency behavior during non-load operation (3, 4).

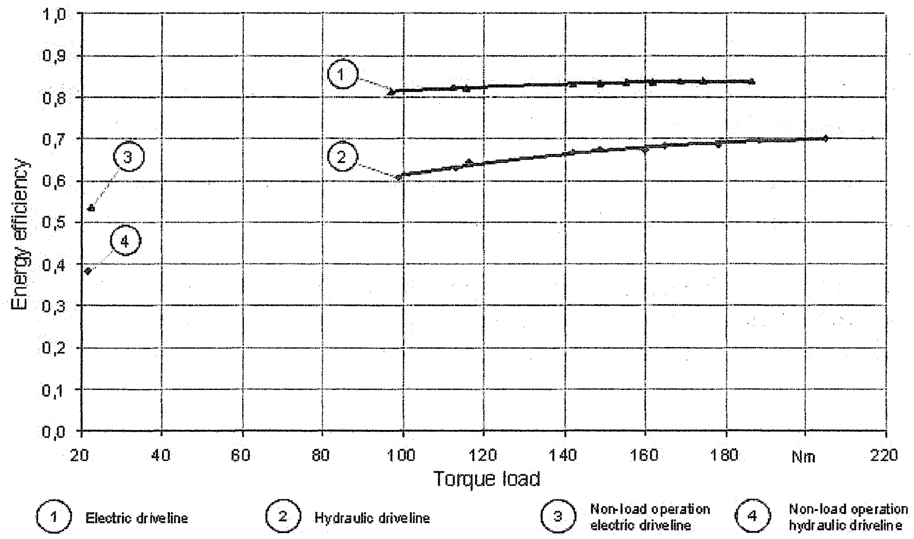


FIGURE 3. Energy efficiency of the hydraulic and electric driveline during typical dynamic load cycles tested for different capacity utilizations

The differences are similar to the stationary tests. During the full load operation cycle the electric driveline is about 16 percentage points more efficient then the hydraulic one. If machine capacity is only partially used the advantage even increases up to 20 percentage points.

For manufacturers beside energy efficiency additionally installation size and power-to-weight ratio are interesting aspects especially in mobile working machines.
The main disadvantage results of the 3.9 times larger electric motors whereby positioning of the drive units near the module is restricted. Instead the generator as part of the electric power supply is more compact compared to the hydraulic pumps if the installation space for connecting the hydraulic hoses is mentioned, too. To complete the electric power supply additional installation space is necessary for the rectifier, the control and supply units but their positioning is only slightly limited.
Less critical then expected is the total mass of the electric driveline. In spite of the approximately 3 times heavier electric-mechanic converter (in the electric supply generator and switch case with rectifier and auxiliary unit is mentioned) and the additional cooling system for the electric driveline the total mass is only 124 kg higher compared to the hydraulic powertrain. The power-to-weight ratio of the driveline increases thereby about 21%. But when comparing the drives it is necessary to keep in mind that the used electric drives are taken from stationary industrial applications and are only adapted. Optimized design enables competitive power-to-weight ratios between 1.25 and 1.5 kg/kW (WEH, 1998) or even 1 kg/kW for special hub motors for traction drives (WECK & ERHARD, 2000).
Comparing the designs of the header drives is difficult because of the mechanical drive shafts which are used in the hydraulic standard solution. Here beside the installation size also the simple module assembly without restrictions in positioning is advantageous for the electric alternative compared to the multi-part hydraulic solution with mechanical transmission to the header.

CONCLUSION: The project identifies electric drivelines as a highly efficient alternative especially for hydraulically driven machines with spatial spreaded modules. Enhancements in energy efficiency between 14 to 20 percentage points are feasible when replacing closed circuit hydraulic systems. Open circuit systems which are often working with several drives powered by one pump even increases the potentials.
A mayor aspect for future applicability is the further improvement of power-to-weight ratio and installation size. Therefore manufacturers of mobile machines have to define their needs to encourage further research and development work by scientist and component supplier.

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