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Electric single wheel drive for mobile agricultural machinery

At the TU Dresden, research has been done on the driveline electrification of mobile agricultural machines, especially for tractors, for many years. Numerous projects have proven the potential of electric drives compared to conventional concepts. Electric motors offer a growth in functionality at justifiable expenses for traction drives. The following article discusses electric single wheel drives for mobile agricultural machinery and gives an overview of the current research work.

Keywords
Electric propulsion technology, single wheel drive

Abstract
Landtechnik 65 (2010), no. 5, pp. 368-371, 3 figures, 1 table, 7 references

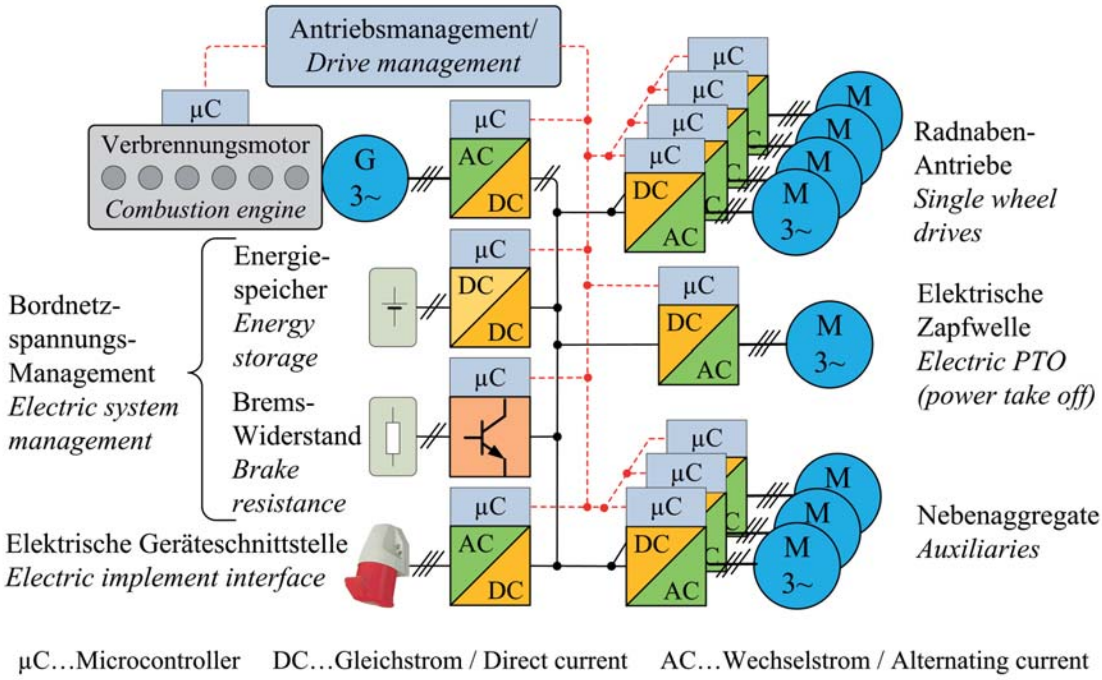
The growing demand on biomass and food will require an increase of productivity and efficiency of agricultural machinery in the future [1]. In tractors, an increase of productivity has been accomplished by innovations focused on the drive train [2]. This includes continuous variable transmissions, an increase of the maximum speed, increase of pull, pto and hydraulic power as well as multi-axle-concepts and tire design.

An important focus of the development on new drive concepts is the increase of efficiency, cost reduction and extension of functionality [3]. An essential characteristic of the new systems are controllability and number of control options, which are currently realised by hydraulic drives. Electric drives acting as an alternative compared to hydraulic drives due to their better controllability, efficiency and space utilisation [4]. The present developments of the automobiles and commercial vehicles lead to a higher acceptability of electric drives in agricultural machinery. Studies show that a mass production of electrical and electromechanical components will enable a reduction in costs [5].

As a result of a long-time research at the Technische Universität Dresden a diesel-electric drive train has been developed and integrated into a research vehicle based on technical expertise and current requirements, **figure 1**.

The drive power is supplied by an engine with a coupled generator (MGU). The generator converts the mechanical into electrical energy which is provided to an intermediate direct current link with a voltage of 400 to 750 V. A mechanical linkage of the drives does no longer exist. Thus the power supply is decoupled from the drives. The speed of the drives does not influence the speed range of the engine and reduces the number of operation points at a known characteristic line. The optimisation of the fuel consumption characteristic and the emission characteristic can be done by the demand of electrical power. The MGU itself can always be understood as a closed system.

Fig. 1



Distributed drive concept for a diesel-electric tractor

A drive management controls all loads appropriate to their demands, which obtain power from the intermediate direct current link. An electric implement interface supplies implements with electric power. As known from the mechanical PTO, the entire engine power has to be provided. For conventional implements the PTO can be driven by an electric motor as an option to provide engine speed independent power. An electric system management limits the voltage of the intermediate direct current link if the capacitor is fully charged. An energy storage device also absorbs energy peaks if alternating loads occur. The reduced dynamic demand to the engine effects lower fuel consumption and emission. A reasonable accumulator capacity has to be defined according to the range of applications.

Single-wheel-drive with promising capability

The research vehicle with the 90 kW drive train is currently realised with four identical wheels. The conversion allows a reduction of number of parts of the drive train and thus the moving parts. Similarly the varieties of parts are reduced by increasing the number of identical parts. A comparison of mass and cost does not show significant disadvantages of the electric driven tractor, as shown in **table 1**.

The single wheel drive offers the most comprehensive advantages due to its functionality. The exact controllability of torque allows an accurate wheel ground slip control. The optimal wheel ground slip can be adjusted per wheel through the known wheel speed, torque and vehicle speed. Likewise specific acceleration and deceleration of the wheels allows to influence the vehicle dynamic (active yaw or torque vectoring) for an obvious understeering or oversteering. The effect is caused by the longitudinal vectors of the wheels rather than by wheel orientation.

The exact adjustment of the wheel torque allows also defined torque ramps and torque limits which results in more accurate component dimensioning by reduced impact loads and known vibration and load cycle behaviour.

An improvement in efficiency is also a result of the optimal sized drive components. The conversion of energy is carried out nearby the engine and within the wheels. Long transfer distances and conversion steps are not applicable. Particularly the single wheel drive offers advantages in structural integration. The drive train, which is currently distributed in the vehicle, can be moved into the rim of the wheel. The released space can be utilised by other components.

Larger steering angles can be realised by an optimised steering mechanism through the reduction of mechanical drive shafts and U-joints. The reduction of mechanical transmission elements and easy wheel mountings assist the development of tractive force optimised chassis suspensions e.g. for multi axle vehicles. The fix ratio of tire diameter disappears by the mechanical decoupling of front and rear wheels which leads to reduced tire wear.

However, a recognizable optimisation effort is needed to obtain the numerous positive characteristics. Electric single wheel drives will be competitive compared to conventional drives, if an integration of the drive components can be realised

Table 1

Summarised comparison of weight and cost for a 90 kW tractor with conventional driveline and diesel-electric single wheel drive

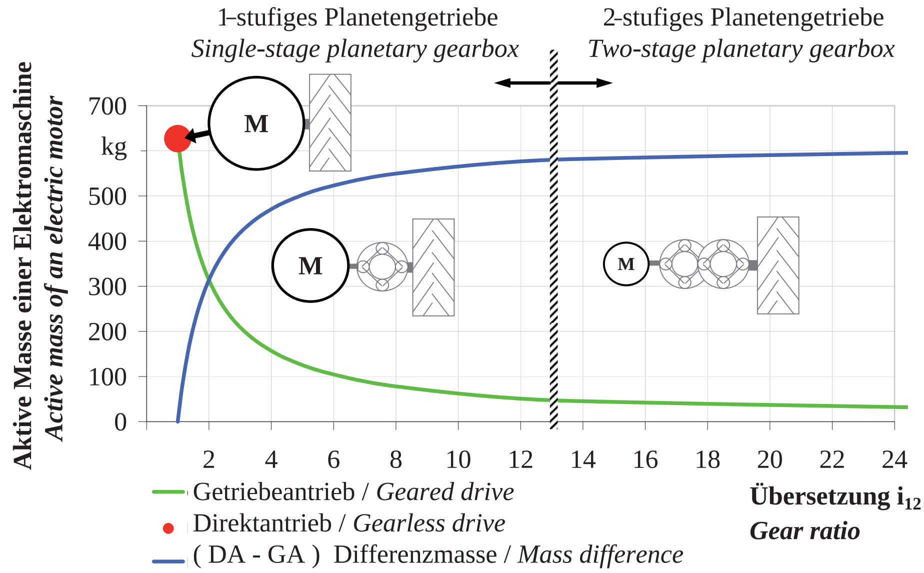
Basistraktor ***Base tractor***					
Fahrzeugrahmen, Kabine, Verbrennungsmotor, Kühlerpaket, Felgen, Reifen, Hubwerke, Tank, Kleinteile *Frame, cabin, combustion engine, cooling, rims, tyre, lifting units, tank, small parts*			2 697 kg	30 676 €	
Konventioneller Antriebsstrang ***Conventional drive train***			**Diesel-elektrischer Einzelradantrieb mit integrierten Radnabenmotoren** ***Diesel-electric single wheel drive with integrated wheel-hubs***		
Zentral-/Verteilergetriebe, Achsen mit Radvorgelege, Gelenkwellen, Ölvorrat *Central and transfer gearbox, axes with final drive, transmission shafts, oil storage*	1 141 kg	16 800 €	Radmotoren, Generator, Radvorgelege, Leistungselektronik, Einzelradaufhängung *Wheel drives, generator, final drives, power electronics, independent suspension*	1 214 kg[1)]	16 710 €[2)] (12 672 €[3)])
Gesamtfahrzeug *Entire vehicle*	**3 838 kg**	**47 476 €**	Gesamtfahrzeug *Entire vehicle*	**3 911 kg**	**47 386 €**
			Bilanz *Balance*	+73 kg	-90 €

[1)] Optimale Gestaltung der Antriebskomponenten / *Optimal designed drive components.*
[2)] Eigene Prognose / *Own prediction.*
[3)] Studie des VDE zur möglichen Kostenentwicklung [5] / *VDE study to suspected cost trends [5].*

in order to achieve a high power density and thus a low vehicle weight. The use of standard off the shelf components instead of specific application tailored design for the electric single wheel drive would amplify the disadvantages in weight and non dampened mass compared to current mechanical and hydraulic drive train concepts.

A further possibility to increase the power density of the electric drives is the increase of the motor speed by using reduction gear sets [6]. In **figure 2** a comparison of mass between direct and geared drives is presented. Both drives are synchronous motors with a force density of 28 kN/m² and an air gap diameter of 630 mm which excite a nominal wheel torque of 7 300 Nm. With an increase of the gear ratio the required motor torque will be reduced and thus the length of the stator. A ratio of i = 5 reduces the mass of the motor to 20 % compared to a direct drive. The additional effort in gears, which are often

Fig. 2



Active mass of an electric motor with an air gap diameter of 630 mm with respect to the gear ratio planetary gears, is acceptable above a ratio of three. Concept comparisons have shown that gears are essential for vehicles with a high torque demand [7]. Above a certain gear ratio the disadvantages have to be evaluated which are caused by efficiency losses, small manufacturing tolerances or gear cost and how they will affect the certain concept.

Furthermore the power density can be increased by improved magnetic materials, a higher number of pole pairs and more efficient cooling techniques.

To obtain the same tractive forces as conventional tractors, the wheel drives have to get the appropriate size. Thus the load spectra and force characteristics of the wheels have to be known. A further challenge is the high torque at low speed on the field and a high road speed during transportation. The constant power ratio is done in conventional tractors by gear steps.

Tractor with single wheel drives

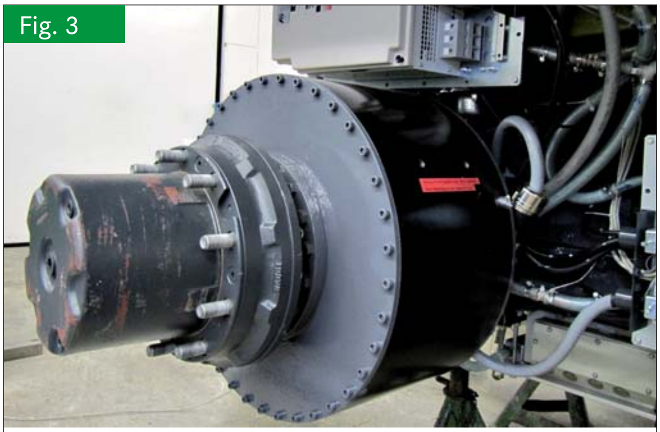
The research tractor is equipped with two wheel drives at the rear axle. The drives are carried out with modular components, **figure 3**.

The motor, which is connected to the final drive, is linked to the main frame. To realise a low cost research vehicle standard power electronic components were used. However the vehicle provides all possibilities to study the dynamic and static behaviour of the diesel-electric drive train. In a further development stage all components (motor with cooling, gear and break) are integrated within the rim to meet the defined requirements. The achieved power density of the integrated wheel hub is significantly higher compared to the modular system. Further research work will be necessary to continue increasing the power density (**table 1**).

Conclusions

Electric drive systems with modular and integrated wheel drives for agricultural machines are developed and studied at the professorship of agricultural machines and technology. These systems are transferable to mobile working machines, tractors and implements with driven axles. Beside a simplification of the drive train, electric single wheel drives offer a growth in functionality and efficiency compared to conventional systems. However electric drive systems with standard components often have disadvantages in weight and cost. By integration and utilisation of the physical characteristics the weight of the drives can be considerably reduced. A cost-weight-comparison shows the advantages of the single wheel drive concept. Further research has the main objective to optimise cooling to increase the power density, increase packing density and simplifiy design to reduce production cost.

Fig. 3



Wheel drive hub with modular components. Photo: TU Dresden

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