Harms, Hans-Heinrich

Potentials of embedded engine- and transmission-controls

The situation of agriculture worldwide requires the use of more agricultural engineering technologies. The shortage of resources leads to systems which decrease wasting energy. One important point is the optimization of an embedded engine- and transmission-management system for mobile working machines. In the following the potential of these systems and possible cost savings are explained and future developments of electrical drive-systems are discussed.

Keywords
Mobile working machines, embedded engine- and transmission-management, variable PTO-drive

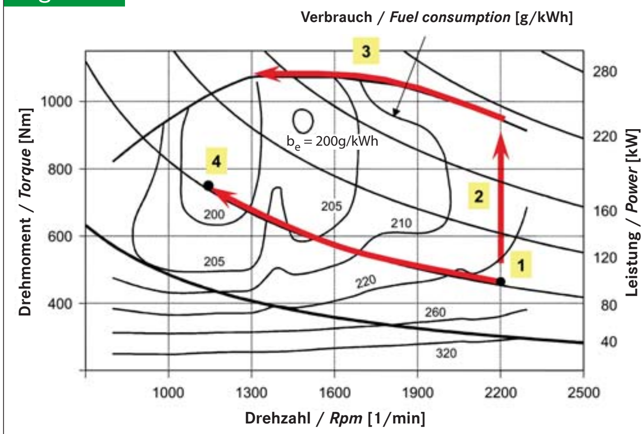
Abstract
Landtechnik 65 (2010), no. 3, pp. 164-166, 2 figures, 5 references

In the coming 40 years, the world´s population will grow by approximately 50 % to about 9.2 billion, while the arable land available per capita will decrease by approximately 65 % [1]. Therefore, the yield per area unit must increase by 50 % worldwide within the next 20 years. Only machinery used professionally can meet these requirements. At the same time, the size of these machines must grow so that the products can be generated at low cost and with the lowest possible energy expenditure.

Interaction of engine and transmission

The maximum working speed of agricultural machinery is determined by several interacting factors, namely the requirements of the crop to be processed, the driving speed, and the design-related capacity of the implement. This means that the combination of these parameters sets the limit above which the machine cannot work optimally. Since working speed demands keep growing, the machines are generally driven at maximum speed. The individual working process thus requires a certain engine speed and torque which must be provided by the diesel engine. If the engine can supply the necessary torque at a given engine speed, the process runs as desired. If the diesel engine cannot provide the torque, the working speed necessarily decreases because the power requirements are too high. In the characteristic curve of the engine (**figure 1**) this means that the operating point (1) first increases at a constant engine speed (2) until the maximum torque is reached. If the torque keeps growing, the engine speed diminishes accordingly (3). The driving speed drops, which leads to a reduction of the maximum possible torque. If a conventional stepped transmission is compared with a stepless unit under this aspect, the engine speed of the latter can be fixed while the driving speed can nevertheless be reduced. With regard to the characteristic curve of the engine, this means that the torque of the original engine operating point (1) is kept constant. The advantage is that the engine can be operated in the maximum power range and therefore the power requirements of the machine can be satisfied.

Fig. 1



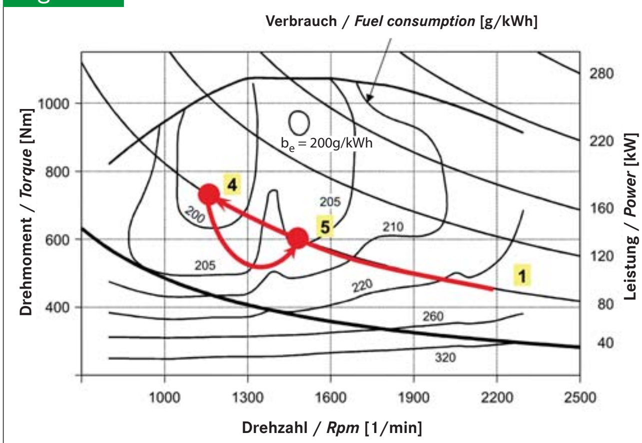
Engine characteristics (Muschel-diagram) of a diesel engine [2]

A stepped transmission obviously does not allow a certain engine speed to be set because the engine speed and the driving speed are always coupled. This shows the benefit of a tractor management system with a stepless transmission. The variable adjustment of the transmission ratio, which in addition does not require any intervention from the operator, enables the management system to choose the engine operating point freely. The working process requires a certain power to be provided by the engine. Since the engine speed can be set regardless of the driving speed, the diesel engine must only supply the necessary power. If this is possible, a consumption-optimized operating point can be chosen. In **figure 1**, the original operating point (1) on the power hyperbola would have to be shifted in the direction of point (4). As soon as the crops to be processed are not homogeneous, the danger exists that power requirements increase sharply and exceed the maximum power provided at the given engine speed. As a result, the engine could be stalled. A management system must choose the engine speed such that a certain torque reserve is always available. This reserve allows a sudden increase in power requirements to be compensated for until the engine management has adapted the transmission ratio and the engine speed so that the stalling of the diesel engine can be excluded. If the operating point (4) cannot be reached because the power requirements cannot be fulfilled by the engine, the management system sets an engine speed which realizes minimum fuel consumption for the required power. The various adjustment options of a powersplit stepless transmission in combination with a management system therefore provide a demand-oriented engine speed. The advantage for the user is either higher area capacity per time unit or lower fuel costs per area unit. During PTO work, however, the problem is that the engine speed is fixed because the PTO shaft is connected to the output shaft via fixed stepped transmissions. In addition, PTO-driven implements are generally designed such that the working process is optimized at a given engine speed. These engine speeds are standardized and are generally reached at the rated speed of the diesel engine (about 2 200 1/min or less in the case of an “economy PTO”). If a PTO-driven implement is operated with a tractor, the diesel engine must be run at a fixed speed regardless of whether the potential output is needed there or could be provided at a lower engine speed. The currently available management system options only allow a freely chosen driving speed to be realized at a given engine speed. To optimize the work process or fuel consumption, it is imperative that the engine speed be decoupled from the PTO shaft. The “stepless PTO shaft” is certainly no new topic. In the past, its realization was impossible due to the costs, the necessary construction space, or excessive power loss depending on whether the power is transmitted hydrostatically or by a powersplit transmission. If a stepless PTO-shaft were used, the engine speed would depend exclusively on the power requirements under all conditions of tractor work and would no longer be rigidly bound to the PTO speed. It would also be possible to choose a favorable operating point for combined operation (**figure 2**, point (4)), of course under the same conditions which apply to the traction drive. The prevention of diesel engine stalling, however, can be more difficult. For this purpose, not only the power requirements of the traction drive, but also those of the additional PTO-drive must be taken into account, and a certain reserve must be created for both. The optimal operating point is not always the point of lowest fuel consumption (4), but an operating point characterized by low consumption and sufficient power reserves (5).

Potential for engine and transmission control

Current management systems set the transmission ratio automatically in order to reach certain defined goals. These objectives are mainly based on the optimization of the work process and its costs. The limits of the current systems are set by the dependence of the transmission ratio on the driving speed determined by the operator. Different studies, e.g. by Seeger [3], indicate that this allows fuel consumption during ploughing to be reduced by 25 %. Of course, this depends on the individual reference point used for the studies. A suitable management system enables the system balance to be improved. The potential of a tractor management system is even greater if

Fig. 2



Engine operating point for a PTO-drive [2] interaction is extended to include additional components. The use of a stepless or partially powersplit PTO shaft, the integration of the hydraulic system into the management system, and the extension of implement-tractor communication allow the entire power output and the working functions of the tractor to be controlled [4].

Electric drives instead of hydraulic units?

The VDMA Fluid Power Association commissioned a study [5] which examined different exemplary machines under the aspect of how great the chances are to replace hydraulic drives by electric units. The key technology for their mobile use, however, is the provision of the necessary electric power and their ability to be combined with mounted implements. In a currently offered tractor with a diesel-electric drive, the battery required for a purely electric drive would weigh approximately 7 t given a specific electric energy of 200 Wh/kg, which would not be sensible. Pure battery operation is currently also not practicable in mobile machines with long full-load cycles, e.g. combines. Due to the high expenses for Li-ion batteries, bipolar lead batteries are considered an alternative. Their specific energy density and output are higher. However, even such a battery still weighs approximately 700 kg. The costs and the availability of the raw material for the permanent magnets represent further problems if the number of users is too large. The expected focus of development in this field of agricultural engineering mainly includes battery technology (greater energy and power density at acceptable costs) and higher power density in electric machines. In 10 years, about 5 % of the fast-running rotatory drives in mobile machines could probably be electrified. Under the conditions of high output, relatively low engine speed, and linear drive systems, however, no alternatives to hydraulic drives are available.

Conclusions

The intelligent, automated optimization of interaction between the engine and the transmission can possibly lead to an improvement of overall efficiency in mobile machines and, hence, to cost reductions of approximately 20 % and more. The use of a PTO-shaft whose rotational speed is independent of the engine speed increases this potential further. In addition to the hydraulic drives frequently used today, electric actuators can be used here. This makes the integration of the consumers even easier. The first types of mobile machines with hydraulic drives have already been developed to a point where they are ready for series production. The motivation for these developments is very different. On the one hand, the use of electric hybrid drives is intended to provide recuperation potential for individual drives, the possibility of downsizing the combustion engine, and an operating point shift. On the other hand, the motivation for the use of electric drives in a tractor, for example, does not lie in energy recuperation, but in the demand-oriented control of power take-off units and the supply of tractor-mounted implements with electric power. The efforts which are currently being made to develop such machines indicate that potential for the increasing use of electric rotatory drives is seen.

Literature

[1] Deutscher Bauernverband (Hg.): Bilanz und Positionen 2008/2009. Geschäftsbericht des Deutschen Bauernverbandes. http://www.bauernverband.de/?redid=172728&layout=print, Zugriff am 28.04.2010

[2] Schumacher; A. und H.-H. Harms: Potenzial von Traktormanagementsystemen mit leistungsverzweigten Getrieben. In: WVMA e. V. Wissenschaftlicher Verein für Mobile Arbeitsmaschinen (Hg.): Tagungsband zu „Hybridantriebe für mobile Arbeitsmaschinen“, Februar 2007, S. 17–29, http://www.fast.kit.edu/download/DownloadsMobima/002_beitrag_ILF_harms.pdf, Zugriff am 28.04.2010

[3] Seeger, J.: Antriebsstrangstrategien eines Traktors bei schwerer Zugarbeit. Dissertation. TU Braunschweig, ILF, 2001. Shaker Verlag, Herzogenrath, 2001

[4] Gugel, R. and Tarasinski, N.: Inifinitely variable PTO transmission. In: VDI-Max-Eyth-Gesellschaft (Hg.): Tagungsband LAND.TECHNIK AgEng 2009 – Conference Agricultural Engineering. VDI-Berichte Nr. 2060, VDI Verlag GmbH, Düsseldorf, 2009, S. 441–444

[5] Forschungsfond Fluidtechnik im VDMA (Hg.): 400 Volt auf der mobilen Arbeitsmaschine – wird die Elektrik zu einer ernst zu nehmenden Konkurrenz? Abschlussbericht der Forschungsstelle am Institut für Landmaschinen und Fluidtechnik der TU Braunschweig, 2009

Author

Prof. Dr.-Ing. Dr. h. c. H.-H. Harms is Director of the Institute of Agricultural Machinery and Fluid Power of the TU Braunschweig, Langer Kamp 19a, 38106 Braunschweig, E-mail: h.harms@tu-bs.de

Note

The article is based on a lecture given at the 9th VDI agricultural engineering symposium “Land.Technik für Profis: Traktor – quo vadis?” in Marktoberdorf on February 22nd and 23rd, 2010.