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Fundamentals of efficiency benchmarking of mobile machine drive systems

Due to steadily increasing fuel prices and problems caused by CO_2-emissions, the efficiency of mobile machines becomes more and more important. Within the development process this leads to an increasing relevance of efficiency as assessment criterion and requires detailed efficiency analyses. The fundamentals of efficiency benchmarking of mobile machine drive systems are the knowledge of the drive system characteristics on the one hand and the machines' working condition profiles on the other hand. Within this paper these aspects are presented in general and exemplified by two hydraulic systems of a combine.

Keywords
efficiency, analyse, benchmark, working condition profile, drive, hydraulic system, mobile machine, combine harvester

Abstract
Landtechnik 66 (2011), no. 6, pp. 426–429, 3 figures, 1 tables, 6 references

The drive system characteristics are determinative of the mobile machines efficiency. To analyse and benchmark the drive systems efficiency behaviour simulation is a suitable tool, especially for drives with multiple functions. This approach facilitates an analysis of each function within several operating conditions. However, a prerequisite is a precise modelling of the components and modules. Therefore, next to the use of loss models and equations presented in the literature, the use of measured characteristic lines and diagrams is to be aspired as well as the verification of the simulation models with measurement data. Anyhow, simulation requires assumptions, especially the modelling of potential drive concepts. Sensitivity analyses are helpful to investigate the assumptions influence on the results.

Regarding the efficiency of hydraulic systems, pumps and motors often play an important role. By Rahmfeld et al. [1] is exemplarily presented how to model their efficiency behaviour on basis of measurement data. Other possibilities are summarized and compared by Kohmäscher [2]. Further losses occur within pipes, hoses, fittings and valves because of flow resistance as well as in hydraulic cylinders due to friction and leakage.

However, next to losses of components, the layout of the hydraulic system plays a substantial role. Since the characteristic efficiency behaviour of the fundamental system layouts is circumstantially presented in literature, e.g. Lang [5], only the new and the previous hydraulic system of a combine are presented in the following.

New and previous hydraulic system of a combine

The layouts of the new hydraulic system used in the Claas Lexion 770 and of the previous system (Claas Lexion 600) are depicted schematically in **Figure 1**.

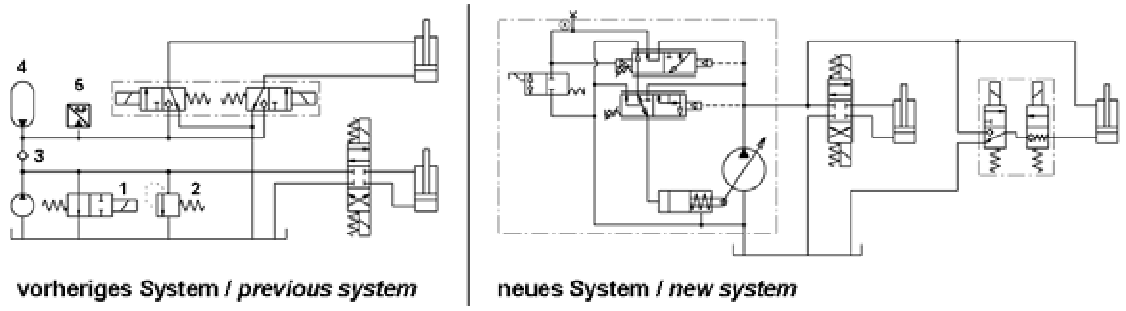
The previous system is a constant flow system with a constant pressure subsystem fed by a gear pump (max. 48 l/min, max. 180 bar). The subsystem consists of a check valve (3), an accumulator (4) and a pressure sensor (5) and enables an efficiency increase due to a less frequently activated circulation lock valve (1). The use of the subsystem makes sense for functions, which require low flow rates, but are high frequently actuated. An example of these functions is the adaption of the cutterbar to uneven ground (auto contour).

In contrast, the new hydraulic system is a constant pressure system with a variable displacement pump (max. 114 l/min, max. 205 bar). To achieve an optimal efficiency each function is designed so that it works barely under the constant pressure level. This enables a comparable efficiency level to load sensing systems. Furthermore it features the advantage of a higher dynamic, whereby the functionality of auto contour significantly benefits.

Working condition profiles – fundamental basis of efficiency benchmarking

Modelling the drive system characteristics is an essential part of efficiency analyses, but apart from the mobile machines working conditions a clear conclusion of the drive systems efficiency is impossible. Especially with regard to drive systems

Fig. 1



Hydraulic system layouts according to [4]

Table 1

Example of a working condition profile

Betriebspunkte/*Operation points*		**Hydraulikfunktionen/*Hydraulic functions***				**Zeitanteile [%]/*Duration [%]***
Motor *Engine*	**Hydraulik *hydraulic***	**Schneidwerk *cutterbar***	**Auslaufrohr *unloading auger***	**Radialverteilerbleche *radial spreader plates***	**Lenkung *steering***	**Beispiel *example***
Unter Last *On-load running*	Straße/*street*				aktiv/*active*	9,13
	Feld/*field*			schwenken/*swivelling*	aktiv/*active*	14,18
	Schneidwerk heben *cutterbar lifting*	heben *lifting*		schwenken/*swivelling*	aktiv/*active*	0,67
	Schneidwerk CAC *cutterbar CAC*	auto contour *auto contour*		schwenken/ *swivelling*	aktiv/*active*	64,94
	Auslaufrohr 1 *unloading auger 1*	auto contour *auto contour*	ausschwenken *swivelling out*	schwenken/*swivelling*	aktiv/*active*	1,33
	Auslaufrohr 2 *unloading auger 2*	auto contour *auto contour*	einschwenken *swivelling in*	schwenken/*swivelling*	aktiv/*active*	1,33
Leerlauf Idle running	Straße/street					5,61
	Feld/*field*			schwenken/*swivelling*	aktiv/*active*	2,15
	Auslaufrohr 1 *unloading auger 1*		ausschwenken *swivelling out*	schwenken/*swivelling*	aktiv/*active*	0,33
	Auslaufrohr 2 *unloading auger 2*		einschwenken *swivelling in*	schwenken/*swivelling*	aktiv/*active*	0,33

with multiple functions, various power demands occur with different durations and require analyses for the specification of working condition profiles.

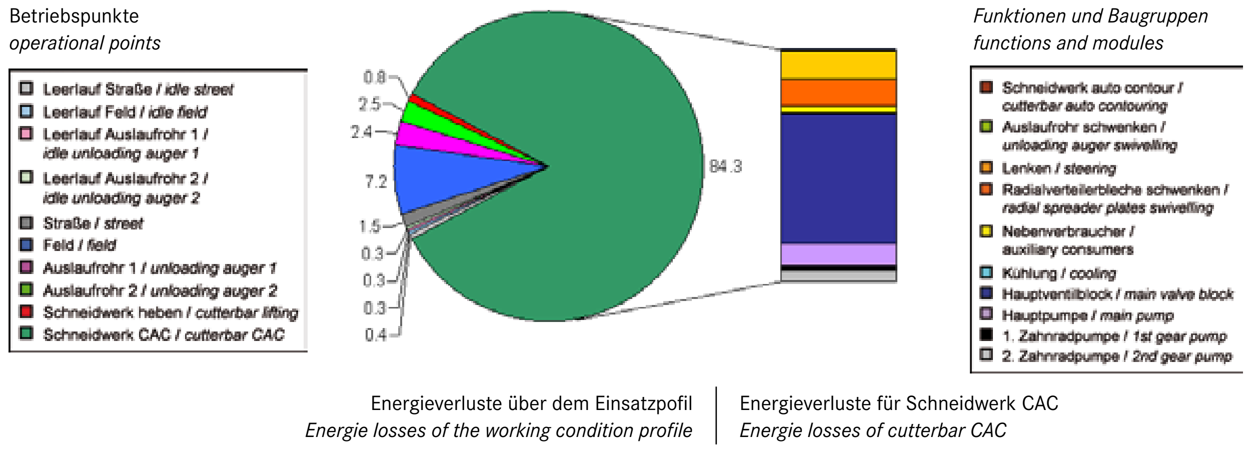
To reduce the quantity but not the quality of the specification the relevant functions of the drive system have to be identified. These are continuously operating and frequently used functions, whereas those which are used only very few times during operating the machine and have low performance requirements can be neglected.

For each identified function the corresponding performance requirements and its duration have to be defined. This is a process on which the machine type has a major influence. Due to their load cycle, the drives of wheel loaders and fork lift trucks have nearly continuously varying performance requirements. To benchmark the drive systems efficiency for such working conditions a method has been developed by Deiters [5]. In contrast, other machines like combines and forage harvesters have working cycles with typical operating points which can be simplistically regarded as quasi-stationary. The number of these operating points depends on the regarded drive system and on the machine type itself.

Furthermore, especially for harvesters the environmental conditions have a crucial influence. Resulting from different harvested crops and varying harvest conditions due to weather conditions and geographical influences etc. the performance requirements and its duration vary. To consider these influencing factors, the specification of several working condition profiles is useful. To provide the required data, the relevance of condition monitoring and telemetry systems, like the Claas Telematics presented by Hamacher [6], increases. The data base of such systems enables analyses of the typical working conditions and its duration for the customers' machine use and therefore the specification of several profiles. Latter are the basis of fundamental efficiency analyses and the drive systems benchmark.

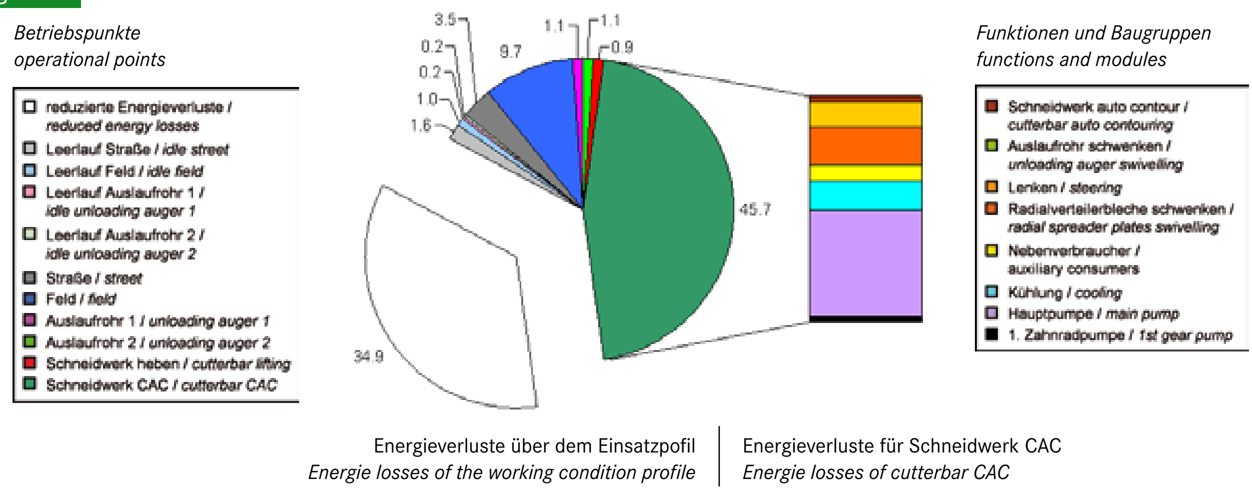
Table 1 represents a working condition profile of the Claas Lexion 600 hydraulic system. The identified main hydraulic

Fig. 2



Efficiency analysis of the previous hydraulic system

Fig. 3



Efficiency analysis of the new hydraulic system

functions beside the considered auxiliary consumers are shown as well as the analysis results of the typical operating points together with the active functions. The corresponding duration is exemplarily given for the wheat harvest in Mecklenburg-Vorpommern in 2009. Depending on the working condition profile the duration of 'street' operating varies up to 50 percent.

Efficiency analyses and benchmarking – Results of the drive system examples

On basis of simulation models fundamental efficiency analyses are only possible in cooperation with working condition profiles. They enable the identification of the operating points with the highest power losses on the one hand and with the highest energy losses on the other hand. The difference of these both considerations is the relevance on the drive system's overall efficiency during machine life time. For example an operating point with high power losses but a small duration might have altogether relative low energy losses. With regard to drive systems with different functions and the corresponding power requirements, a high functional degree of efficiency is not equal to low energy losses and vice versa. Therefore the working condition profiles are the key factor to benchmark mobile machine drives on basis of total energy losses during machine life time.

In the following some results of the efficiency analyses are presented for both hydraulic systems. In **Figure 2** the analysis results of the previous hydraulic system are exemplarily shown for the working condition profile representing the wheat harvest in Mecklenburg-Vorpommern in 2009. The pie chart on the left depicts the amount of energy losses of each operating point. It becomes clear that the operation point 'cutterbar CAC' is the key factor for the hydraulic systems efficiency, which is caused by the duration (table 1) among other things. The bar graph on the right illustrates the amount of losses of the functions and modules within the operating point 'cutterbar CAC'. The losses of the main valve block consisting of the circulation lock valve and pressure relief valve (figure 1, (2)) are dominant. This is the outcome despite the fact, that the time of an activated circulation lock valve is significantly reduced by the constant pressure subsystem. Consequently, changing to another hydraulic system layout was necessary for a further efficiency increase.

Figure 3 depicts the results of the new hydraulic system for the same working condition profile. Within the pie chart the reduction of energy losses compared with the previous system is added. Depending on the working condition profile the reduction of energy losses differs between 21 and 45 percent and represents the key factor for the efficiency benchmark. Furthermore it becomes obvious, that the operation point 'cutterbar CAC' has likewise the highest relevance. Going into more detailed analyses of this operating point, the bar graph illustrates the main influence of the main pump on the losses. Further ideas to increase the efficiency exist and will be investigated and benchmarked.

Conclusions

Modelling of drive systems is useful to analyse the efficiency of mobile machine drives. However only in cooperation with specified working condition profiles the simulation enables meaningful analyses and benchmarks on basis of energy losses. The varying typical operating conditions of mobile machines for example due to regional circumstances can be considered by the specification of several profiles. Taking these aspects into account, a fundamental decision for or against the development and implementation of an optimized or new drive concept is guaranteed. With the inclusion of each machine's drive, analyzing and benchmarking of a complete machine is possible.

Literature

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