Alternative Module Drives for Mobile Working Machines

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Requirements resulting from material processing

Yield map of sugar beets, field Hergern (Germany) October 2001

<table>
<thead>
<tr>
<th></th>
<th>Relative flow variability [%]</th>
<th>Standard deviation of yield [kg/ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine `02</td>
<td>78</td>
<td>96,2</td>
</tr>
<tr>
<td>Combine `03</td>
<td>120</td>
<td>181,1</td>
</tr>
<tr>
<td>Mower `01</td>
<td>29</td>
<td>15,8</td>
</tr>
<tr>
<td>Mower `02</td>
<td>78</td>
<td>32,8</td>
</tr>
<tr>
<td>Beet harvester `02</td>
<td>71</td>
<td>260,7</td>
</tr>
<tr>
<td>Maize Chopper `02</td>
<td>134</td>
<td>235,0</td>
</tr>
<tr>
<td>Maize Chopper `03</td>
<td>41</td>
<td>108,9</td>
</tr>
</tbody>
</table>

Increased machine efficiency by:

- Dynamic machine adaptation (KUTZBACH) → closed-loop module speed control
- Closed loop module control systems (BÖTTINGER)
- Increased driveline efficiency
Objectives

Problem:
Which technology fits future demands?

Assessment of alternative drive line concepts for usability in mobile working machines

Criteria:
• satisfying future requirements
• overall efficiency
• power to weight ratio
• overall size of the module drive and the peripheral equipment
• design aspects
• costs
Field Tests

Hydraulic driveline: Operational behaviour
Power-to-weight ratio $m_p$

Hydraulic driveline: Typical Loadcycle
- $\eta_t$ driveline
- $\eta_t$ module
- $\eta_t$ transmission

Electric driveline: Operational behaviour
Power-to-weight ratio $m_p$
Carrier Big-X with easyCollect
Hydraulic Header and Intake Drive

1. Pumps
2. Motorvgearing
3. Hydr. Intake Drive
4. Hydr. Header Drive
5. Gearing
6. Intake Module
7. Split Gearing Header
8. Mech. Driveline Header
9. Chaindrive Gearing

- Pressure Sensor
- Flow rate Sensor
Diesel-electric Header and Intake drive (without Cooling System)

1. Synchronous Generator
2. Power switch
3. Rectifier
4. Capacitors DC-Link & Braking resistors
5. Control and Safety
6. DC-Link (400-750 V)
7. Motor with Converter
8. Planetary Gearing
Diesel-electric Solution
1. Header, Intake und Feeding pump at Engine Gearing
2. Hydraulic Header drive with mech. driveline
3. Summation gearing
4. DLG PowerMix Module with mech. Interface
5. Hydraulic Intake drive
6. Hydraulic pump system with 100 ccm variable displacement pump
7. Hydraulic Interface DLG PowerMix (DLG_{hydr})
8. DLG PowerMix Drawbar Test Vehicle
Results

- Operational behavior during field tests
- Efficiency during stationary operation
- Efficiency during dynamic operation
- Power-to-weight ratio
- Power density
- Costs
Operational Behavior
- Hydraulic and Electric Intake Drive during Field Tests -

![Graph of Operational Behavior]

- Most common operation point

Flow rate

Pressure

-100
0
100
200
300
400
500
[bar]

0
20
40
60
80
100
120
160
[l/min]

Current

0
50
100
150
200
250
300
[A]

0
500
1000
1500
2000
2500
3000
[rpm]

{\textcolor{red}{I_N}}

{\textcolor{red}{I_{max}}}

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Efficiency of module Drives depending on load

\(n_{\text{Diesel}} = 1750 \text{ 1/min; } x_{\text{th}} = 8 \text{ mm}\)

1. Hydraulic intake drive
2. Hydraulic header drive with mechanic transmission
3. Electric header drive
Efficiency Benefits of the Electric Driveline
Energy efficiency during typical load cycles

- 1. Electric driveline
- 2. Hydraulic driveline
- 3. Non-load operation electric driveline
- 4. Non-load operation hydraulic driveline
Power-to-weight ratio of modules and drivelines

- Obvious disadvantages at the electric module drives:
  ➡️ Averaged electric drives 3 times heavier than hydraulic ones

- New approaches enable advantages for the driveline at a glance:
  ➡️ Electric header drive: 11.3 kg/kW
  ➡️ Hydraulic-mechanic header drive: 15.9 kg/kW

- The powertrain for header and intake at a glance:
  ➡️ Diesel-electric approach: 689.6 kg  17.2 kg/kW
  ➡️ Hydraulic approach: 565.6 kg  14.1 kg/kW

But: comparability of the used systems is limited

=> Series Production vs. Prototype
Size and Power Density of electric motors

Hydraulic Motor (Series production)  Electric Motor (Prototype)

- 7.6 dm³  29.6 dm³
- 3.566 kW/dm³  0.916 kW/dm³

(by HARMS)
Costs of acquisition

Electric Prototype
- Electric Motor
- Safety Concept
- Cooling System
- Power Transmission
- Mountings
- Electric Driveline Series

Electric Series Production
- Hydraulic Driveline Series

Hydraulic Series Production

*) estimated
(Careful) Costs of Operation

Fuel costs:
- 1.30 €/l
- 1.90 €/l
- 6.94 €/l
- 4.75 €/l

Costs hydraulic oil:
Summary

Advantages of the diesel-electric driveline:

- Closed loop control of the drives and feedback of the process parameters enables easy integration into driveline managements system
- Efficiency benefits at a wide range of the operation map of about 16 percentage points (between 13.5 to 30 percentage points)
- Efficiency benefits during typical load cycles between 14 to 20 percentage points

Disadvantages of the diesel-electric driveline

- Power-to-weight ratio of the total driveline is about 22 % higher
- Power Density is about 3.9 times inferior
- Amortization or increased acquisition costs after the total useful life
The future power train design in mobile working machines?

Example: Combine harvester

Decentralized unit including power electronics and motor - electric drive unit (EDU) -

Integrated EDU

Centralized power electronics

Decentralized motors

Central EDU for modules with comparable requirements
Conclusions

**Diesel-electric drivelines**

- are an additional alternative in mobile working machines
- show high efficiency even under low work load
- improve control and adjustment
- have highest benefit in systems with very large variable requirements
- allow direct use of electricity from solar and fuel cells

Thank you for your attention!

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