Potentials of Vehicle Dynamics and Slip Control for Mobile Machinery enabled by an Electric 4WD

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Content

• Short overview on existing control systems

• Brief description of tire-ground dynamics

• Features of Rigitrac EWD120, simulation and experimental tests

• Results

• Summary
Tractor
- 3pt hitch draft control (EHR)
  Objective: - Pulling force, position and combined control
  - Slip-control in pulling force control mode
  - Vibration damping system for transport
- Adjustment of drive power (injection quantity)

Self propelled machines
- Pressure or volume flow control of the axle/wheel motors
Drive Train Concepts

- Fixed speed ratio of axles with leading
  - Mechanical tension in drive train
  - Disengagement of all-wheel-drive on streets and large steering angles
- Transfer of motor power to one wheel

- Adjustment of axle speeds
- Lower tire wear and stress in drive train
- Lockable differential for all-wheel drive

→ Fusion of the systems to combine the advantages

- Torque vectoring
- Reduction of mech. parts within the drive train
- Individual vehicle traction
- Optimized chassis concepts
- Oversizing (M↑) of the wheel motors
- Cost

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Potential of vehicle dynamics and slip control
Advantages of Electrical Drives

- High efficiency, especially in partial load range
- 4 – quadrant operation (motor / generator)
- Very good controllability, variable limit of the characteristic
- Space optimized structure
- Short-term overload capability of the motors
- Low-wear
Tire-Ground Contact and Power Transmission

a – driven wheel
b – driven wheel w/o long. force
c – pulling wheel

direction

Utilization of a Tractor

I highest energy efficiency
II max. draw bar power

→ Optimization of fuel cost and time

Control Approach

Steering, Different soil conditions, non-zero draft force angle ($\gamma$)
- Slip control by wheel torque adjustment
- Yaw control by torque vectoring

→ Verification in simulation model and on test stand

**Diesel Electric Single-Wheel Drive**

**combustion engine**
- 95 kW at 2000 1/min
- Liquid cooling

**generator**
- 90 kW at 2000 1/min
- Liquid cooling

**DC Link**
- 350 – 650 V
- Max. 700 V

**brake resistor**
- \( P_{\text{nenn}} = 40 \text{ kW} \)
- \( P_{\text{max}} = 200 \text{ kW} \)

**suspension**
- 4-wheel steering with hydro-pneumatic single wheel suspension

**4 wheel drives**
- Tire 540/60 R28
- \( v_{\text{max}} = 65 \text{ km/h} \)
- \( M_{\text{nenn}} = 8200 \text{ Nm} \)
- \( M_{\text{max}} = 14000 \text{ Nm} \)
- \( P_{\text{nenn}} = 33 \text{ kW} \)
- \( P_{\text{max}} = 44 \text{ kW} \)
- Liquid cooling
Simulation Model

input signals

vehicle body and wheels

contact dynamics

electric motors

Engine and Generator

output of result

identification, control, logic

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Rigitrac in Test Environment

Objectives:
- handling of the system
- reproduce defined loads
- robust system controller (static and dynamic)
- efficiency of drive system

Measurements:
- diesel motor: n, M
  optional: fuel consumption
- DC Link: current and voltage
- 2 wheel motors: n, M
- component temperatures

- 2 x 90 kW asynchronous motors at front axle for load simulation
- additional gearboxes are available for high torques
Results – Torque Vectoring

- **Yaw rate during steering from 0° to 4° at 7 km/h**

![Graph showing yaw rate and time](graph.png)

- *_with control*
- *w/o control*

**Legend:**
- Blue line: Steering angle
- Green line: Yaw rate with control
- Red line: Yaw rate w/o control

**Axes:**
- Yaw rate [deg/s] on the y-axis
- Steering angle [deg] on the y-axis
- Time [s] on the x-axis
Results – Torque Vectoring with Yaw Control

yaw rate and torque difference during cornering at 10 km/h

slip of rear axle and steering angle change during cornering at 10 km/h

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Results – Slip Control at Constant Speed

- Torque [Nm]
- Slip [%] and controller status
- Speed [m/s]
- Motor speed [rpm]
Results – Slip with Yaw Rate Control

slip and drawbar force - 12 kN and \( \gamma = 20^\circ \) at 7 km/h - w/o control

slip and drawbar force - 12 kN and \( \gamma = 20^\circ \) at 7 km/h - with control

Yaw rate at different drawbar forces – 7 km/h
Summary

- Electric drives enables more accurate control strategies for mobile machinery
- Electric single wheel drives allows dynamic power distribution to handle any particular situation
- Torque vectoring improves motion stability and vehicle handling
- Single wheel slip control coupled with torque vectoring allows to optimally utilize drive train power
Thank you for your attention!

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