Development of Hybrid Strategies with Optimization and Engine-in-the-Loop Testing

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Overview

1. Introduction
   - Motivation - Background
2. Hybrid Electric Vehicle (HEV) Modeling
   - Model Setup
   - Numerical Optimization
   - Results of Simulation
3. Test and Verification
   - Test-Bed Setup
   - Simulation vs. Test-Bed
4. Outlook and Next Steps
5. Summary
1. Introduction
Motivation for HEV

- Major benefits of HEVs: significant improvement of fuel consumption.
- Therefore, it is a promising concept to contribute to the future $\text{CO}_2$-targets.
- On the other hand, powertrain complexity is increased dramatically for HEV’s.
- Beside the dimensioning of the internal combustion engine and the electric components, the operating strategy of the hybrid powertrain is of particular importance to optimize the vehicles fuel consumption.
- For the best possible solution elaborate numerical optimization strategies must be employed in dependency of numerous vehicle parameters.
- Objective of the following investigations is the minimization of the vehicle’s fuel consumption in the New European Driving Cycle (NEDC).
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4. Summary
2. Model Setup and Numerical Optimization

Model Setup

- Capability of Hybrid Electric Vehicles:
  - Recuperative Braking
  - Boosting
  - Load Point Shifting
  - Start/Stop
  - Electric Driving

Topology of the powertrain:
2. Model Setup and Numerical Optimization

Model Setup

- A numerical simulation model of a vehicle with mild hybridization was set up in GT-Suite.

- The 6-cylinder SI engine, the electric components and the vehicle were modeled in accordance with a close-to-series powertrain.
2. Model Setup and Numerical Optimization

Model Setup

- The battery, the electric motor and the SI engine were characterized with maps to provide fast simulation times.

- Operating strategies were defined with the GT-EventManager.

Operating Strategy

- El. Drive
- Load Point Shift
- Boost
- Recup. Braking
- Start/Stop
2. Model Setup and Numerical Optimization

Numerical Optimization

**Background:** One simulation of the complete NEDC-cycle takes approx. 5 minutes

**Target:** Best possible strategy in reasonable time range

**Approach Metaheuristics**

**Example Particle-Swarm-Optimization**

a) Definition of a search space
b) Equally distributed solution approach
c) Particles are moving in the direction of the best solution

- No guarantee to find the best solution but
+ Reasonable calculation time ranges with numerous parameters
2. Model Setup and Numerical Optimization

Numerical Optimization

- Combination of 4 methods:
  - Monte-Carlo
    - Initial solutions
  - Particle-Swarm-Optimization
    - High diversity, large search space
  - Surface-Fitting
    - Try to improve best known solution
  - Genetic Algorithm
    - Recombination of solutions and randomized parameter modifying
  - Downhill-Simplex
    - High specialization, small search space
2. Model Setup and Numerical Optimization

Numerical Optimization

- An interface to GT-Suite was created to control the simulations and parameters automatically.
- Parallel calculations are automatically started by the optimization tool.
- Parameter ranges can be defined.
2. Model Setup and Numerical Optimization

Numerical Optimization

- First approach of optimization:
  - One parameter for Load Point Shifting in separated areas within the NEDC
  - One parameter for all Gear-Shift Speeds
  - One parameter for max. Electric Driving Velocity

Specific fuel consumption
NEDC [%]

- 17.8 %
- 20.2 %

better solutions with heuristic methods in same time range as results with included DOE
2. Model Setup and Numerical Optimization

Numerical Optimization

- Different parameters for each section of the NEDC:
  - Load Point Shifting
  - Gear-Shift Speed
  - Maximum Electric Driving Velocity

![Graph showing specific fuel consumption](image)

- Conv.
- DOE: 3 Parameters
- Optimizer: 3 Parameters
- Optimizer: 18 Parameters

- Reductions:
  - 17.8%
  - 20.2%
  - 33%
2. Model Setup and Numerical Optimization

Results of Simulation: Load-Spectrum

**Tendency of operating strategy:**
Long phases of electric driving combined with aggressive load point shifting to balance the battery’s state of charge.
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3. Test and Verification
Test-Bed Set-Up

- Engine in the Loop Test-Bed
  - Engine
  - Load: asynchronous machine
  - Sensors & Actuators
  - Test bench equipment from ETAS
3. Test and Verification
Test Bed Set-Up

Matlab Simulink is used to combine the GT-RealTime HEV model with the ETAS Experiment Environment.
3. Test and Verification
Simulation vs. Test-Bed

Comparison: Good correlation between simulation and test bench results
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4. Outlook and Next Steps

Next Steps

- Further enhancements of the model
  - The engine’s mean friction pressure must be considered in dependency of the oil temperature.
  - A thermal model of the engine will be developed and verified with the test bench results.
  - Light-off behavior of the exhaust system to control the emissions.

- Numerical optimizer will be enhanced with additional optimization methods for integrating a larger amount of parameters.
5. Summary

- A numerical simulation model of a vehicle with mild hybridization was set up in GT-Suite.
- The components were characterized with maps to provide real-time capability.
- In addition, a numerical optimizer based on several heuristic methods was developed to minimize the vehicle’s fuel consumption for the NEDC.
- Optimized operating strategies were found that improved the fuel consumption significantly.
- The most promising concepts were verified on a engine-in-the-loop test-bed.
Thank you for your attention!

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