

Optimal Control of Waste Heat Recovery Systems Applying Nonlinear Model Predictive Control (NMPC)

Philipp Petr, Christian Schröder, Prof. Dr.-Ing. Jürgen Köhler, Dr. Manuel Gräber ASME ORC 2015 - 3rd Seminar on ORC Systems, Brussels, October 14th 2015

Waste Heat Recovery System in a Long Distance Bus

Total vehicle model (thermal, longitudinal dynamics)



Boundary Conditions

institut für thermodynamik



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Waste Heat Recovery System in a Long Distance Bus







1. Transient heat source temperature and mass flow rates





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- 2. Interactions between different subsystems





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- 3. Predicted states offer futher potential for energy recovery





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- 1. Transient heat source temperature and mass flow rates
- 2. Interactions between different subsystems
- 3. Predicted states offer futher potential for energy recovery
- 4. ORCs shows a high grade of nonlinear behavior in transient operation
 - ⇒ Linear approaches not feasible in all operating conditions
 - ⇒ Nonlinear approaches are beneficial, but complex
- Nonlinear Model Predictive Control (NMPC) is one method to take this challenge
- NMPC is a repetetive solving of an optimal control problem for finite prediction horizons





Development of a transient mathematical long-distance bus model with a waste heat recovery system

Development of a software tool chain for NMPC

Development of a differentiable High-Speed Model of the ORC for NMPC

Virtual test drive in the European Transient Cycle to test the concept







Block Diagram of the Nonlinear Model Predictive Control





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Block Diagram of the Nonlinear Model Predictive Control





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Software Tool Chain





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Computation Time







Benchmarking NMPC in Partial Load Conditions





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Expander inlet pressure





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Expander inlet enthalpy





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Expander power





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Pump work





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⇒ Higher net power output due to (optimized) ORC part load operation





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Conclusion and Outlook

- Implementation of advanced control strategies are necessary for small ORC systems operating under transient boundary conditions
- Development of a software tool chain to realize a prototype NMPC
- Development of an ORC High-Speed Model
- Virtual Test Drive of a long distance bus proved the potential of NMPC in the part load section of the European Transient Cycle (ETC)

Outlook

- Improvement of the High-Speed Model regarding computational time and accuracy
- Implementation of physically motivated expander models
- Proof of concept by means of an ORC test rig









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