48V Vehicle Simulation Approaches – Detailed through System Level

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11/6/2017
Outline for Today’s Presentation
2017 GT-SUITE NA Conference

1. Background – 48V Demo Vehicle Project
2. Simulation Goals and Motivation
3. Approach
4. Models and Applications
   1. Detailed Engine
   2. Complete vehicle system model with FRM Engine model
   3. Cosim
   4. Engine State
5. Conclusions
48V Mild Hybrid Demonstration Vehicle

Key Features

- 2.7L V6 GTDi
- 6-speed automatic
- 48V eBooster (electric centrifugal compressor)
- 48V BAS Motor Generator Unit
- BorgWarner supervisory controls
- Partnering with Ford and Mahle (QCM) for production controls integration

P0 Mild Hybrid Energy Recovery with Boost Assist
48V Enabled Components – eBooster + BAS

**eBooster**
- Minimizes turbo lag, improves efficiency
- "Multiplies" stored electrical energy
- eBooster enables increased engine downsizing or alternatively higher levels of power through a larger turbocharger

**BAS**
- Captures energy typically lost to braking
- Extends Stop/Start
- Provides torque assist
48V Vehicle Simulation Goals and Motivation

Overall Goal
Development and usage of a 48V mild hybrid vehicle system level model for fuel economy studies

Motivation
- Allows investigation of major vehicle changes which would be cost prohibitive in hardware
- Model offers repeatable and controllable tests which allow quantification of fuel economy benefit for subtle changes

Additional Goals
- Boosting system effects on fuel economy and performance
- Platform for controls development
- Fast simulation times which enable investigation using DOE techniques
Simulation Approach

- Model engine to investigate an eBooster and support vehicle model
- Run DOE and optimizations
- Evaluate fuel economy of a mild hybrid vehicle system
- Support vehicle controls development
- Vehicle with Engine State
- Vehicle with FRM
- Detailed and FRM engine
- Co-sim model

4 Model Environments
Simulation Approach

- Model engine to investigate an eBooster and support vehicle model
- Evaluate fuel economy of a mild hybrid vehicle system
- Run DOE and optimizations
- Support vehicle controls development
Detailed and FRM Engine Models

- Used test data to build and validate a detailed engine model over complete operating range.

- Built an FRM using the GT FRM Converter.

- Compared these models using a transient load step test (at 1500 RPM).

Computational time for a 30 second simulation:
Detailed model = 23 minutes; FRM model = 1.5 minutes
Simulation Approach

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Vehicle System Model and Controllers

Model Controllers

Powertrain and Drivetrain Models
Controllers

- Engine – throttle, A/F ratio, spark, fuel-cut
- Boost – waste gate
- eBooster – electrical power
- Transmission and torque converter – shifting and lock up
Controls development

- Evaluated Fuel-cut and Start-stop strategy using the vehicle system model.

- GT native control templates were used to model these strategies.
Fuel Cut and Start-Stop

Quantifying hybrid strategies was possible with native GT control templates
Comparison of Boosted versus Naturally Aspirated Engine

Evaluate boost system effect on US06 Drive cycle

- Two cases – waste gate operated to achieve desired boost and waste gate fully open.
- What is the fuel economy benefit of an open waste gate?
- What is the effect on drivability?

- Manifold pressure comparison indicates significant levels of boost on drive cycle
- Power level can be achieved without boost system
- There is a 3.5% fuel economy benefit
- However, the fuel economy benefit comes with a drivability penalty
Simulation Approach

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- Evaluate fuel economy of a mild hybrid vehicle system
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- Support vehicle controls development

Detailed and FRM engine

Vehicle with FRM

Vehicle with Engine State

Co-sim model
Co-sim with Simulink

- Early version of model using surrogate engine model used to develop controls. Enabled development of detailed and FRM models in parallel.

- BW developed Simulink controls to replace P0 GT controls for:
  - Hybrid Supervisor
  - Brake
  - BAS

Able to use the supervisory controls developed by the Controls team which are also used in the vehicle.
Simulation Approach

- Model engine to investigate an eBooster and support vehicle model
- Run DOE and optimizations
- Evaluate fuel economy of a mild hybrid vehicle system
-支持车辆控制开发
- 模型发动机以研究 eBooster 并支持车辆模型
- 运行 DOE 和优化
- 评估轻度混合动力车辆系统的燃油经济性
Vehicle with Engine State Model

- Replacement of FRM with Engine state reduces the simulation time by 99%
- Generated shift schedules using the GT VKA analysis object
- Evaluated effect of shift design variables on vehicle FE and drivability

DOE variables
- Min speed following upshift
- Max load following upshift
- Engine speed at best FE position
- Engine load at best FE position

Combined Fuel Economy Difference [%] & Average No. of Shifts Difference

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Conclusions

1. Ability to develop models with appropriate levels of complexity allowed timely analysis while achieving goals at all stages of project.

2. FRM model capability to model air system with short run times enabled evaluation of fuel economy versus drivability trade-off on US06 drive cycle.

3. Strong support from partners was a major factor in creation of high fidelity models.
Acknowledgements

BorgWarner 48V Vehicle Demo Team: Keith Van Maanen, Matt Griffen, John Shutty, Shawn Liu, Joel Maguire, Sara Mohon

Gamma Technologies: Jon Zeman and Joe Wimmer
Thank you!