E85 Optimized Engine through Boosting, Spray Optimized GDi, VCR and Variable Valvetrain

Wayne Moore, Keith Confer - DELPHI
Ming-Chia Lai - Wayne State University
19May 2009 Presentation

Project ID: ft_14_confer

This presentation does not contain any proprietary or confidential information
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Overview

Timeline
- Project start: 10/1/07
- Project end: 9/30/10
- Percent complete: 55%

Challenges
- Fuel property differences
- Engine Controls
- E85 fuel economy

Budget
- Total project funding
  - DOE share $2,186,448 (44.5%)
  - Contractor share: $2,724,298 (55.5%)
- 2008 Funding: $1,561,120
- 2009 Funding: $2,094,342

Partners
- Delphi / Wayne State University
- Delphi is the Project Lead
- Interactions with OEM
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Objectives of work

• The objective of this project is to develop and demonstrate an overall engine hardware and control system implementation that minimizes the fuel economy penalty currently seen when bi-fueled ethanol enabled gasoline engines are run on high-percentage ethanol blends. This system could promote consumer acceptance of high ethanol blend fuels and associated gains for the US economy and environment.

• Project objectives completed over the past year:
  – Developed analytical models and defined E85 optimization strategy and hardware
  – Designed and built E85 optimized valvetrain, ignition, pistons and injectors
  – Constructed high temperature / high pressure injector test chamber
  – Evaluated injectors under simulated engine conditions
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Milestones

**Phase 1 (Oct 07 – May 08)**
- Development of Engine Models
- Injector Spray Modeling
- Development of Vehicle Level Model

**Phase 2 (June 08 – Dec 08)**
- Develop Baseline Fuel Specifications
- Baseline Definition of Fuel Injectors, Ignition and Other Components
- Test Chamber Construction
- Baseline Definition & Build of Valvetrain Hardware
- Hardware Verification and Testing

**Phase 3 (Jan 09 – June 09)**
- Injector Optimization Under Simulated Engine Conditions
- Single Cylinder Test Engine Modification
- Steady State Engine Characterization
- On-Engine Verification of Injector Spray Optimization

**Phase 4 (July 09 – Sept 10)**
- Implementation and Test of Ethanol-Optimized Engine
- On-Vehicle Implementation and Test of Ethanol Optimized Engine
- Project Close Out

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**Phase 1**
Applied Research Modeling
- Oct 07

**Phase 2**
Exploratory Development
- June 08

**Phase 3**
Optimization
- Jan 09

**Phase 4**
Implementation & Test
- July 09
- Sept 10
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**Approach**

- Improve E85 fuel economy through increased compression ratio and variable valve actuation.
  - High compression ratio enabled by high octane number of ethanol fuels.
  - Atkinson cycle enables high efficiency – Early Intake Valve Closing (EIVC)
  - Variable Valve Actuation (VVA) provides unthrottled load control over 80-90% of FTP

- Avoid knock with gasoline by lowering effective compression ratio using variable valve timing.
  - Enabled by Dual Independent Cam Phasing (DICP) and 2-Step Valve Train

- Achieve high power density using turbo charging.

- Enable low emissions with stratified cold start for fast converter light-off.
  - Stoichiometric 3-Way catalyst provides cost effective after-treatment
Expected E85 fuel economy improvements based on analysis. An engine with these hardware improvements will be tested in CY 2009 to verify simulation results.
E85 Optimized Engine Project
Speed Load Map (cam selection)

2.0 L LNF Engine
2-Step Torque 1 Bar Map

Baseline Data

FTP

High Lift Cam

Low Lift Cam

- Variable Valve Actuation (VVA), with extended timing range, provides un-throttled load control over 80-90% of FTP drive cycle.
E85 Optimized Engine Project
Piston Geometry Description

• Revised piston to increase CR from 9.2 to 11.85
  – Piston bowl feature to support stratified cold start and spray induced charge motion for split injection
    » Image shown at 20 mm Below TDC (52 Cad bTDC)
  – Valve clearance to allow intended cam phasing
  – Maximum cylinder pressure limit (100 Bar)
    » Limits power density of engine

Photo of E85 project hardware
E85 Optimized Engine Project
2-Step Variable Valve Definition

• 2 Step Variable Valve Actuation (VVA) on intake
  – Low Lift Cam (EIVC)
    » Up to 4000 RPM
  – High Lift cam (LIVC)
    » Up to 6500 RPM

• Production Exhaust Cam
  – Single cam profile
E85 Optimized Engine Project
Cam Phaser Description

• Intake Cam Phaser
  – 80 crank angle degree authority hydraulic intake phaser
    » Authority range determined by GT Power simulation to meet load control window
    » Extended phaser authority enables unthrottled load control from 2Bar to maximum BMEP
  – Cam phasing speed determines “throttle response”

• Exhaust Cam Phaser
  – 50 cad authority

Photo of E85 project hardware
E85 Optimized Engine Project
Ethanol Optimized Fuel Injectors

- **E85 injector features:**
  - Targeted to avoid valves
  - Minimize bore wetting
  - Interaction with piston bowl
    - Stratified cold start
  - 20.4 g/s @10 MPa
  - Increased flow rate and dynamic range for flex fuel
  - Optimize injector driver strategy
  - All samples are characterized at Delphi
**E85 Optimized Engine Project**

**Schematics for spray-visualization**

**Experimental Setup**

- **Phase Doppler**
  - Droplet Distributions

- **High Speed Imaging**
  - Mie scattering
    - Penetration
    - Structure
  - Schlieren
    - Vapor Boundaries

**Test Conditions**

- Pressure 0.4-5 Bar
- Temperature 20-250 °C
- Fuel Temperature 20-90 °C
Comparison of High-speed Mie and Schlieren Spray Imaging (100 C, 1 Bar, E100)

Schlieren

Mie Scattering
Spray – Piston Interaction
(Piston-15 mm, E100, 1.5 ms, 10MPa Fuel Pressure)

\[ \text{T}_{\text{fuel}} \ 25 \text{ C}, \ \text{T}_{\text{test}} \ 25 \text{ C}, \ \text{P}_{\text{test}} \ 1\text{ Bar} \quad \text{T}_{\text{fuel}} \ 60 \text{ C}, \ \text{T}_{\text{test}} \ 210 \text{ C}, \ \text{P}_{\text{test}} \ 3.2 \text{ Bar} \]

Orientation of test chamber
E85 Optimized Engine Project
Wayne State University Optical Engine

Optical Engine

- 2.0 L GM (LNF) Head
- 86 mm Bore
- Transparent Liner
- Optical Piston
- Delphi fuel injector
- Project specific camshafts
  - High and low lift fixed cams
  - Manual cam phasing
Future Work

- The fuel injector test chamber, developed earlier in this project, will be employed to refine the prototype flex-fuel injector designs at pressure and temperature that simulate engine conditions.

- The optical engine will provide spray characterization in a dynamic flow environment with charge motion.

- The boosted engine will be retrofitted with pistons, injectors and valve train hardware. The engine will be tested on a dynamometer to validate fuel economy and performance with E85. The engine will further be used to develop integrated control strategies for E0-E85 fuel blends.

Empirical data will be used to update and refine the analytical models.
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Summary

• Simulation confirmed the basic concept of the project:
  – A combination of increased compression ratio and variable valve actuation applied to a gasoline SI engine can improve the fuel efficiency when high ethanol fuel blends are used. This same variable valve actuation can be used to produce a lower effective compression ratio when the modified engine is run on gasoline.

• Fuel injection is being optimized for robustness to fuel variation of E0-E85
  – Homogeneous and stratified operation are being considered. Stratified for cold start situations and homogeneous for normal running conditions.

• Engine hardware for optimized E85 operation has been designed and built.

• Engine tests will be completed this calendar year to verify results of analytical studies.

• The project is progressing according to plan.