The Application of High Energy Ignition and Boosting/Mixing Technology to Increase Fuel Economy in Spark Ignition Gasoline Engines by Increasing EGR Dilution Capability

Edward J. Keating

March 15, 2013

Project ID #
ACE086

Overview

Timeline

- Start Date: July, 2012
- End Date: July, 2015
- Percent Complete: 25%

Barriers

- Boost device availability with the desired broad map characteristics.
- Spark plug durability with the proposed high energy ignition system.
- Transient control of boost pressure and EGR rate.

Budget

- Total funding: $2,454,140
  - DOE share: $1,277,070
  - Contractor share: $1,277,070
- DOE FY12: $107,067 (through 9/2012)
- DOE FY13: $227,024 (10/2012 - 1/2013)

Partners

- Southwest Research Institute®

Simulation, Ignition & EGR System Application, Engine Testing

Project Lead

- GM

RELEVENCE - Objectives

- Develop and demonstrate the enabling technologies of high energy ignition and the novel use of a charge boosting device with EGR mixer to achieve significant thermal efficiency improvements while meeting U.S. EPA emission standards cost effectively.
- The selected enabling technologies accomplish this by enabling increased levels of EGR to be supplied and tolerated by a spark ignition gasoline engine prior to exceeding customer acceptance limits regarding combustion stability and engine transient response.
- The enabling technologies identified offer the potential additional benefit of using increased quantity and quality of cooled EGR for knock suppression at high load enabling the specification of a higher compression ratio.
- The ability to utilize current, stoichiometric mixture based emission aftertreatment devices is maintained.
- The final solution will be designed and developed to package within the engine compartment of a current GM mid-size vehicle.

APPROACH – Milestones (FY12-FY13)

Milestone	Completion Date
Results of initial 1-dimensional engine and vehicle simulation (Phase 2)	COMPLETE
Results of design, testing, development, and analysis of analysis of novel DCO™ ignition system applied to initial initial GM 4-cylinder engine configuration with baseline baseline EGR/mixing solution (Phase 3)	4Q13

APPROACH - Technical Overview

Technologies that have been demonstrated to increase EGR benefit and dilution tolerance limits …

- Combustion burn duration improvement through hydrogen augmentation of the charge.
- Combustion burn duration improvement through the use of multiple points of ignition (spark plugs).
- Combustion cyclic variation reduction through the use of a high energy, extended duration ignition system.
- Combustion burn duration improvement through the use of increased charge motion (tumble and/or swirl)

APPROACH - Technical Overview

Combustion burn duration improvement through hydrogen augmentation of the charge …

- Higher quality EGR may be generated through the use of the novel dedicated EGR (D-EGR™) concepts developed at Southwest Research Institute® in recent years through the HEDGE II® consortium.
- The concept realizes benefits that have been well documented in the literature regarding hydrogen augmentation of the charge for SI combustion, but is capable of producing the hydrogen without the losses associated with external fuel reformers.
- The hydrogen augmentation is achieved by using the output from a “dedicated” cylinder for EGR that has been produced by combusting a rich mixture.

APPROACH - Technical Overview

Combustion burn duration improvement and/or cyclic variation reduction through enhanced ignition …

- A solution to employ 2 spark plugs per cylinder has been implemented to improve combustion burn duration.
- For a single spark plug option, a novel ignition system referred to as dual coil offset (DCO™) uses two coils in a multi strike mode, but phased so that there is only 1 breakdown event to reduce cyclic variation.

Combustion burn duration improvement through the use of increased charge motion (tumble and/or swirl) …

- A “tumble” inlet port has been implemented in order to produce in-cylinder tumble motion.
- A “swirl control valve” has been implemented to partially block one inlet valve in order to produce in-cylinder swirl motion as required.
- The combination of swirl and tumble may be used together in order to produce a very significant in-cylinder charge motion.

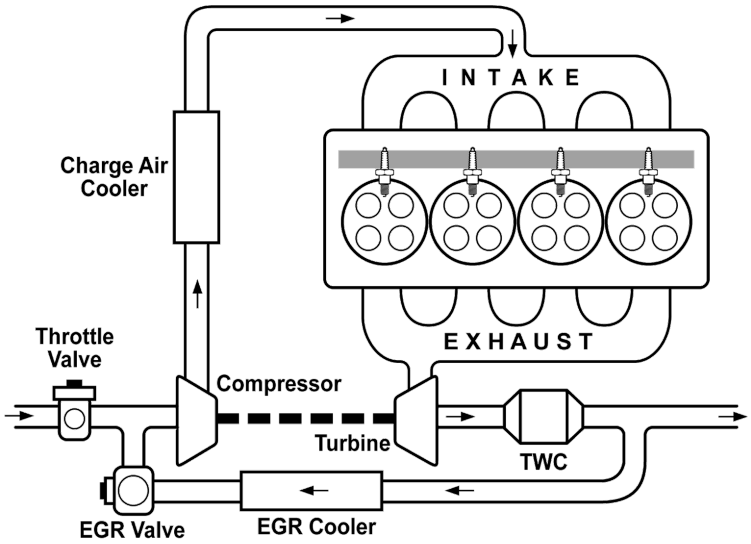
APPROACH - Technical Overview

Synergistic technology shown to enhance the efficiency benefits of Dedicated EGR (D-EGR™) …

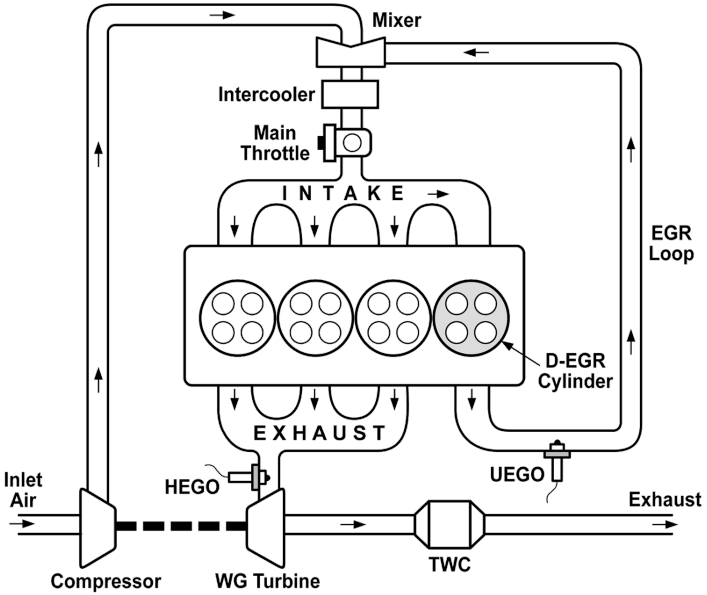
- Intake charge boosting (Turbocharger or Supercharger)
  - Elevated compression ratio due to the knock suppression properties of D-EGR™ is of greater benefit on a boosted engine due to the relatively low CR of a baseline boosted engine.
  - Boost levels and efficiencies are enhanced over traditional boosted EGR systems as the boost device does not have to “pump” EGR.
  - Enables mild downsizing of engine displacement relative to the naturally aspirated baseline engine.

APPROACH - Technical Overview

- D-EGR™ has sufficient energy to eliminate the requirement to “pump” EGR with the charging system.
- Dedicated EGR eliminates the need for proportional EGR valves / sensors, minimizes control complexity



Conventional LPL EGR



D-EGR™

Diagram courtesy SwRI®

TECHNICAL ACCOMPLISHMENTS and PROGRESS

Phase 2 Vehicle Simulation (baseline engine in mid-size GM vehicle) Complete

- 11 engine speed – load points identified that represent ~95% of the fuel energy used during FTP City/Hwy/US06 cycles
- ***These points will be used during engine dynamometer testing to represent "weighted" vehicle fuel economy***

Phase 2 Initial engine simulation complete at 11 engine speed-load points

- Baseline Engine
- Conventional LPL EGR
- Dedicated EGR

Phase 3 Baseline 2.4L NA engine dynamometer testing completed and fuel efficiency baseline established at 11 engine speed – load test points

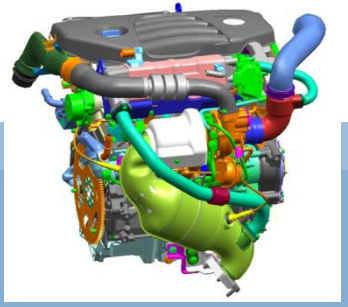
- *Weighted average simulation results were within 1.5% of actual engine test results*

TECHNICAL ACCOMPLISHMENTS and PROGRESS

Phase 3 "Conventional" Low Pressure Loop (LPL) EGR System Status …

- Design completed to apply a "Conventional" LPL EGR system to a current production GM turbocharged engine packaged in current mid-size vehicle
- The 2.0L turbocharged engine **baseline** dynamometer testing has been completed and fuel efficiency established at 11 engine speed – load test points prior to increasing compression ratio, installing DCO™ ignition system, and the addition of a cooled LPL EGR system.
- The 2.0L turbocharged engine has been updated with new high compression pistons, DCO™ ignition system, and cooled LPL EGR hardware.

- ***Testing of the updated 2.0L turbocharged engine has begun. Testing is scheduled to be completed by the end of the 2nd quarter 2013.***



TECHNICAL ACCOMPLISHMENTS and PROGRESS

Phase 4 Dedicated EGR (D-EGR™) System Design Status …

- The detail design and analysis of a new cylinder head implementing the ignition strategy of two spark plugs per cylinder is on schedule.
- The layout of the exhaust system incorporating an application of a D-EGR™ bypass concept has been completed.
- The design work to implement the application of an innovative variable geometry turbocharger to this gasoline engine is proceeding according to plan.
- The intake system with swirl control valve layout has been completed and the detail design work is proceeding per plan.
- The layout of an innovative charge air cooler combined with a pulse suppression mechanism has been completed.

- **D-EGR™** ***system design is scheduled to be completed in the 3rd quarter 2013. Part Acquisition and engine build are scheduled to be completed by the end of the 3rd quarter 2013.***

TECHNICAL ACCOMPLISHMENTS and PROGRESS

Project barriers eliminated or mitigated by application of the selected solutions …

EGR flow capability and boost device availability with the desired broad map characteristics.

- D-EGR™ *is fully separated from turbo machinery*
- D-EGR™ *results in lower exhaust temperatures enabling a VGT turbocharger*

Spark plug durability when used in conjunction with the proposed high energy ignition system.

- *2 spark plug per cylinder provides additional energy to the cylinder without compromising spark plug durability.*

TECHNICAL ACCOMPLISHMENTS and PROGRESS

Project barriers eliminated or mitigated by application of the selected solutions …

Transient control of boost pressure and EGR rate.

- *D-EGR™ provides a consistent level of EGR from a "dedicated" cylinder without the requirement for a proportional EGR valve and the attendant transient response issues.*
- *D-EGR™ alleviates the requirement for the boost device to "pump" EGR so impact on boost response is mitigated.*

COLLABORATION and COORDINATION

Southwest Research Institute® – Sole Subcontractor

- Primary Responsibility
  - Ignition and EGR system Application
  - Engine Testing

- Contributor
  - Engine and Vehicle Simulation
  - Base Engine Hardware Updates
  - Vehicle Engine Compartment Packaging

FUTURE WORK

Milestone	Completion Date
Results of design, testing, development, and analysis of analysis of novel DCO™ ignition system applied to initial initial GM 4-cylinder engine configuration with baseline baseline EGR/mixing solution (Phase 3)	4Q13

FY 2013 …

Complete testing of turbocharged GM 4-cylinder engine equipped with high energy, extended duration DCO™ ignition system and baseline (LPL) cooled EGR system.

- *Compare performance and fuel consumption to baseline naturally aspirated 4-cylinder engine.*
- *Update simulation models as required to improve predictions for future work.*

Complete design and acquisition of hardware to update a turbocharged GM 4-cylinder engine to operate with D-EGR™ , 2 spark plug / cylinder ignition solution and a variable geometry turbocharger.

FUTURE WORK

Milestone	Completion Date
Results of design, testing, development, and analysis of novel boosting/mixing system applied to GM 4-cylinder engine updated with novel D-EGR™ and high energy ignition solution (Phase 4)	4Q14

FY 2014 …

Complete testing of turbocharged GM 4-cylinder engine updated with D-EGR™, 2 spark plug / cylinder ignition solution and a variable geometry turbocharger.

- *Compare performance and fuel consumption to baseline naturally aspirated 4-cylinder engine.*
- *Update simulation models as required to improve predictions for future work.*

Complete design and acquisition of hardware to update a turbocharged GM 4-cylinder engine to operate with a final system solution based on test results to date and updated simulation predictions.

FUTURE WORK

Milestone	Completion Date
Results of design, testing, development, and analysis of final novel boosting/mixing, EGR, and ignition systems applied to GM 4-cylinder engine (Phase 5)	2Q15

FY 2015 …

Complete testing of a turbocharged GM 4-cylinder engine updated to operate with a final system solution based on previous test results and simulation predictions.

- *Compare performance and fuel consumption to baseline naturally aspirated 4-cylinder engine to establish final project performance to objectives.*

SUMMARY

- **Vehicle Simulation (baseline engine in mid-size GM vehicle) is complete**
  - *11 engine speed – load points identified that represent ~95% of the fuel energy used during FTP City/Hwy/US06 cycles*
- **Initial engine simulation complete at 11 engine speed-load points**
  - Baseline Engine
  - Phase 3 “Conventional” LPL EGR
  - Phase 4 Dedicated EGR
- **Baseline 2.4L NA engine dynamometer testing is complete and fuel efficiency baseline has been established at 11 engine speed – load test points**
  - *Weighted average simulation results were within 1.5% of actual engine test results.*

SUMMARY

- **A GM 2.0L turbocharged engine has been updated to Phase 3 specification with new pistons to increase compression ratio, DCO™ ignition system, and cooled LPL EGR hardware.**
  - *Testing of the updated 2.0L turbocharged engine has begun.*
  - *Testing is scheduled to be completed by the end of the 2nd quarter 2013.*
- **The Phase 4 D-EGR™ system design is scheduled to be completed in the 3rd quarter 2013.**
- **The Phase 4 D-EGR™ part acquisition and engine build is scheduled to be completed by the end of the 4th quarter 2013.**