Demonstration of Air-Power-Assist (APA) Engine Technology For Clean Combustion and Direct Energy Recovery In Heavy Duty Application

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Objective

The objective of this project is to demonstrate an APA (Air-Power-Assist or Air Hybrid) engine technology that enables 15% fuel economy improvement for heavy-duty refuse application with low emissions.

Introduction

- During braking, the engine utilizes the braking energy to work as a compressor, pumping compressed air into an on-board air tank. → ***Air Compressor (AC) mode***

- Later, during acceleration, the engine is powered by the stored compressed air with or without burning diesel fuel to get up to speed or until the compressed air is depleted.

→ ***Air Motor (AM) mode***

- Once the vehicle is moving along, the engine converts back to a conventional diesel engine.

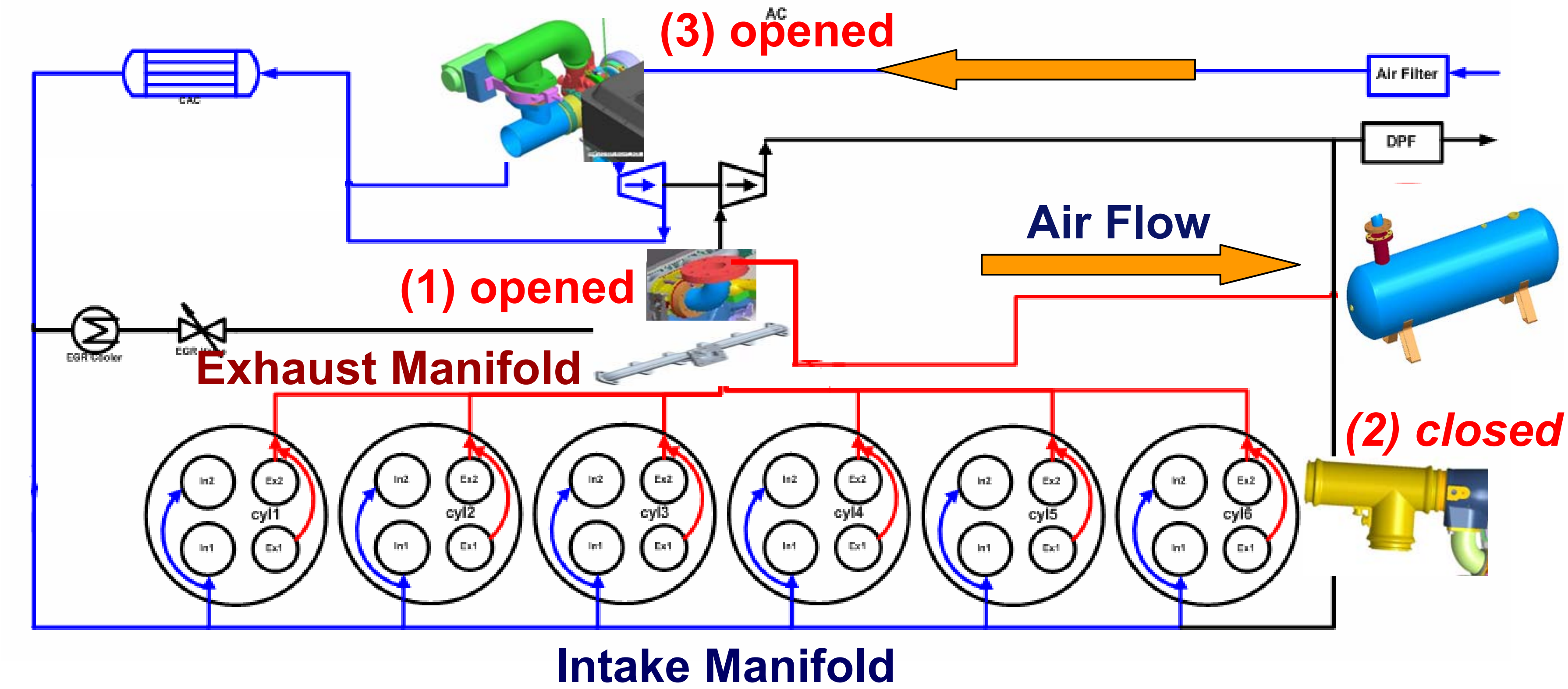
Benefits

- The positive pumping work performed by compressed air is added to the work performed by combustion gas during the gas-expansion stroke. → ***Improvement of Fuel Economy***

- The high boost pressure during engine acceleration helps reducing PM. In addition, the smaller quantity of fuel burned in each cylinder during each cycle leads to lower peak temperature. → ***Reduced Emissions***

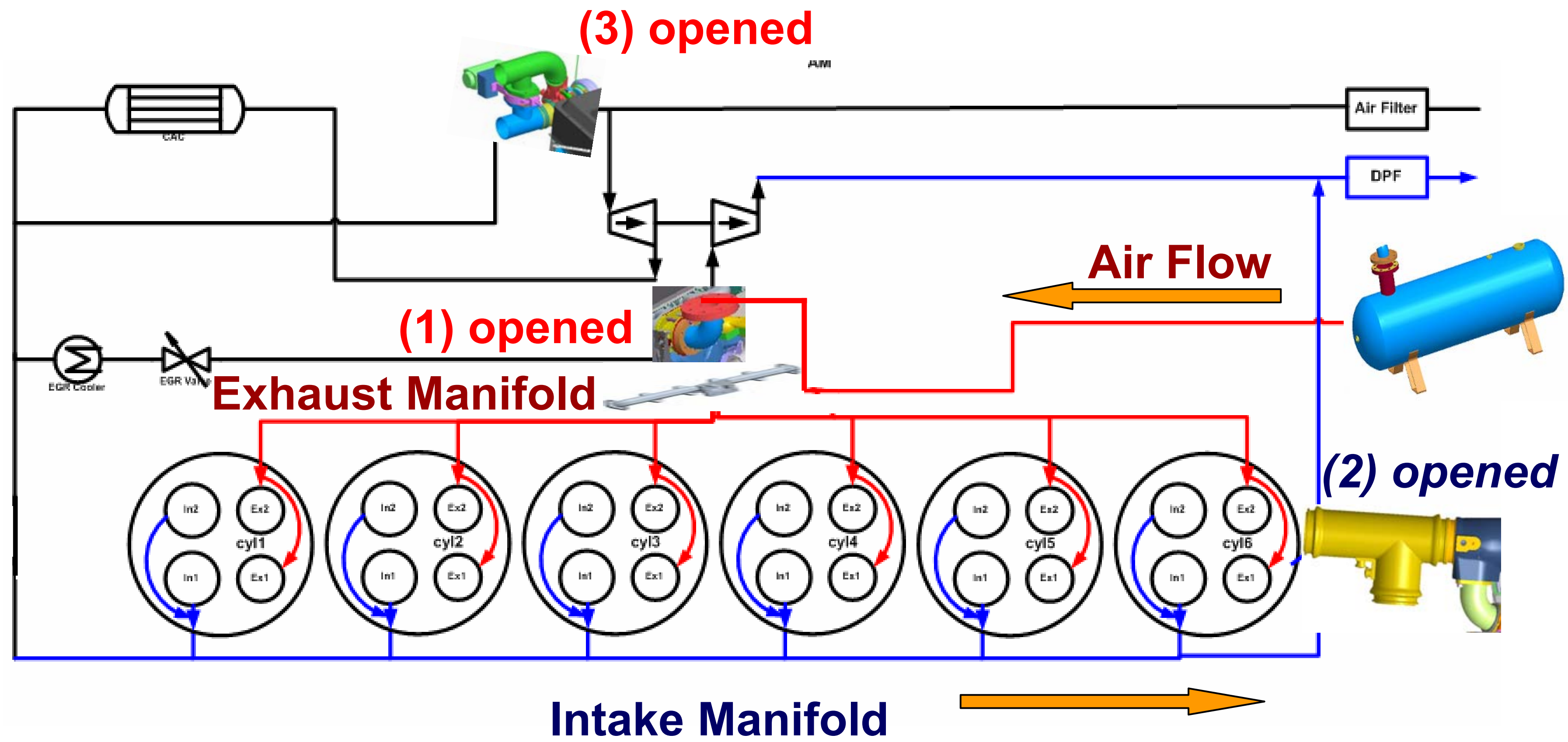
The noise from the sudden exhaust gas blow-down process during engine braking is reduced by minimizing the pressure difference across the engine valves, and the reduced noise is further muffled by the air tank. → ***Reduced engine braking noise***

Air Compressor (AC) Mode: Operating the engine as an air compressor and storing the compressed air in a reservoir



(1)Exhaust 3 way Valve (2)Intake 3 way Valve (3)Compressor bypass Valve

Air Motor (AM) Mode: Operating the engine as an air motor utilizing the stored air



(1)Exhaust 3 way Valve (2)Intake 3 way Valve (3)Compressor bypass Valve

Technical Challenges

- Components
  - Flexible engine valves.
  - High pressure exhaust manifolds.
  - External switching valves.
  - Valve stem seals.

- Control
  - Mode switching control, especially AM to IC.

- Vehicles Installation
  - The compressed air storage component. (Air Tank)
  - External switching valves.

Approach

- Fundamental study

2nd-law thermodynamic efficiency. → AC and AM efficiency

- Components design
  - Hydraulic Valve Actuator system.
  - Stainless steel one-piece exhaust manifolds.
  - Pneumatic switching valves.

- Control development 1-D engine modeling and optimization of valve timings/lifts
  - AC and AM mode control strategy.

Collaborations / Interactions

- **Volvo Powertrain North America**
  - Fundamental study of air hybrid engine design & optimization
  - Air handling system design (external switching valves, exhaust manifold, air storage tank, etc.)
  - Engine installation and Testing.
- **Sturman Industries**:
  - Hydraulic Valve Actuator system
- **University of California at Los Angeles:**
  - 1-D engine simulation
  - Valve timing/lift optimization
  - Control development

Vehicle Simulation Results

Driving Cycles	base (mpg)	APA (mpg)	% Increase
Heavy-Duty Cycles			
WVU City Driving Schedule	3.51	3.87	**10%**
WVU Suburban Driving Schedule	4.48	4.87	**9%**
WVU Interstate Driving Schedule	6.62	6.98	**5%**
Urban Dynamometer Driving Schedule	4.43	4.79	**8%**
Central Business District (CBD_Truck)	3.37	3.80	**13%**
City Suburban Cycle & Route (CSC)	3.91	4.34	**11%**
New York Composite	2.96	3.48	**18%**
WHM	3.04	3.35	**10%**
Bus Cycles			
New York City Transit Bus	2.18	2.57	**18%**
Manhattan Bus cycle	3.04	3.56	**17%**
Central Business District (CBD14)	4.63	5.05	**9%**
BAC cycle - Transit coach	4.04	4.21	**4%**
VPTNA cycles			
Simple refuse	1.09	1.23	**13%**
30-day cycle	3.04	3.31	**9%**

- **There was 4-18% Fuel Economy improvement over a wide range of driving cycles (14 Driving Cycles).**

This APA technology proved improvement of fuel economy on various driving cycles and improvement of fuel economy with APA technology strongly depends on driving cycle.

APA engine system

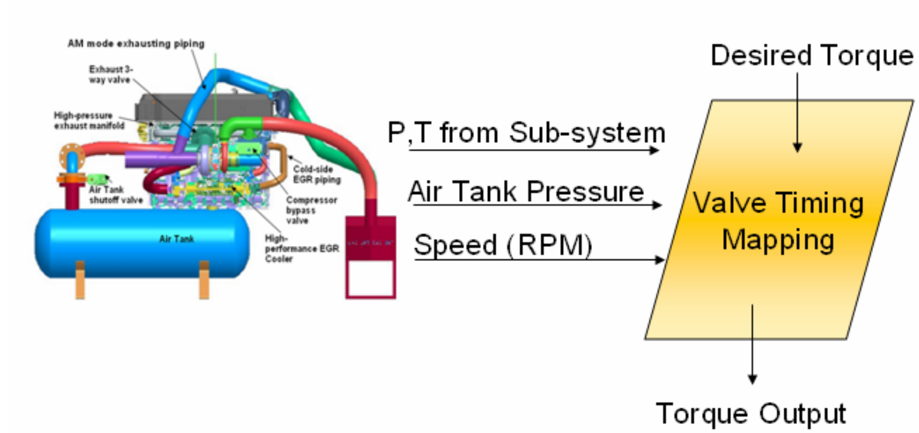
(1) Engine Specification (MD11)

Type and numbers of cylinders	In-line 6 cylinder
Cylinder Diameter (D)	123 mm
Stroke (S)	152 mm
Displacement	10.84
Stroke Ratio (S/D)	1.236
Connecting Rod Length (CL)	225 mm
Connecting Rod Ratio (CL / (S/2))	2.961
Piston compression height	90.8 mm
Piston Mean Speed (max output)	9.12 m/s
Compression Ratio	16:1

(2) Hydraulic Valve Actuator (HVA) system, Sturman Ind.

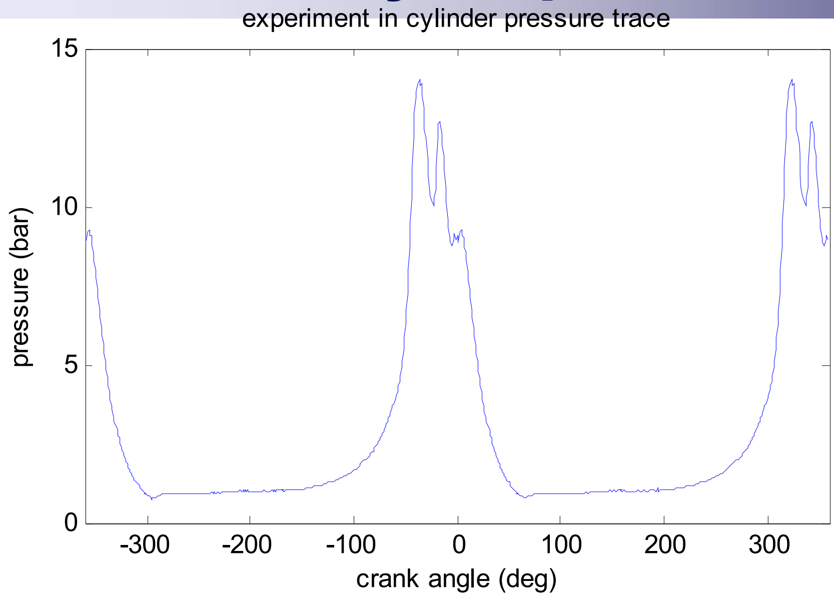
(3) Amplifier Piston Common Rail System (APCRS), Bosch.

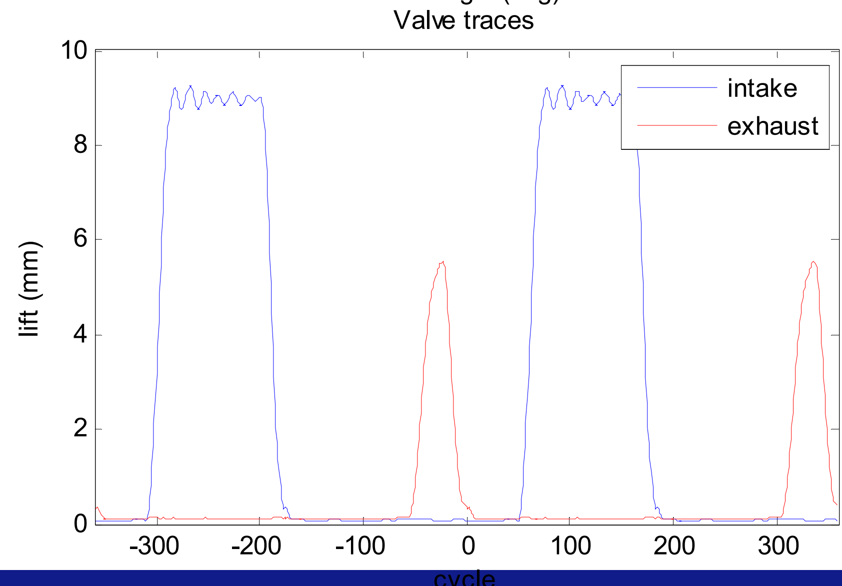
(4) Control System
-ETAS ASCET



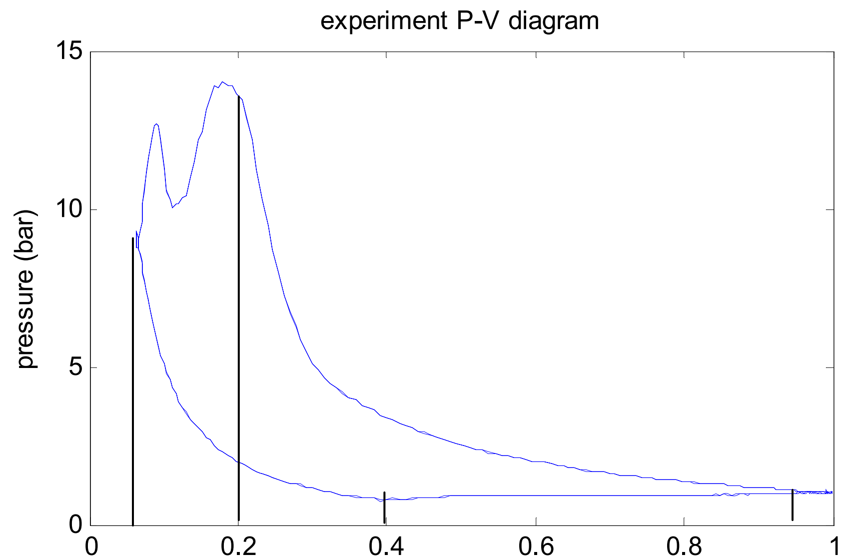
Air Hybrid Engine

Preliminary Experimental Results

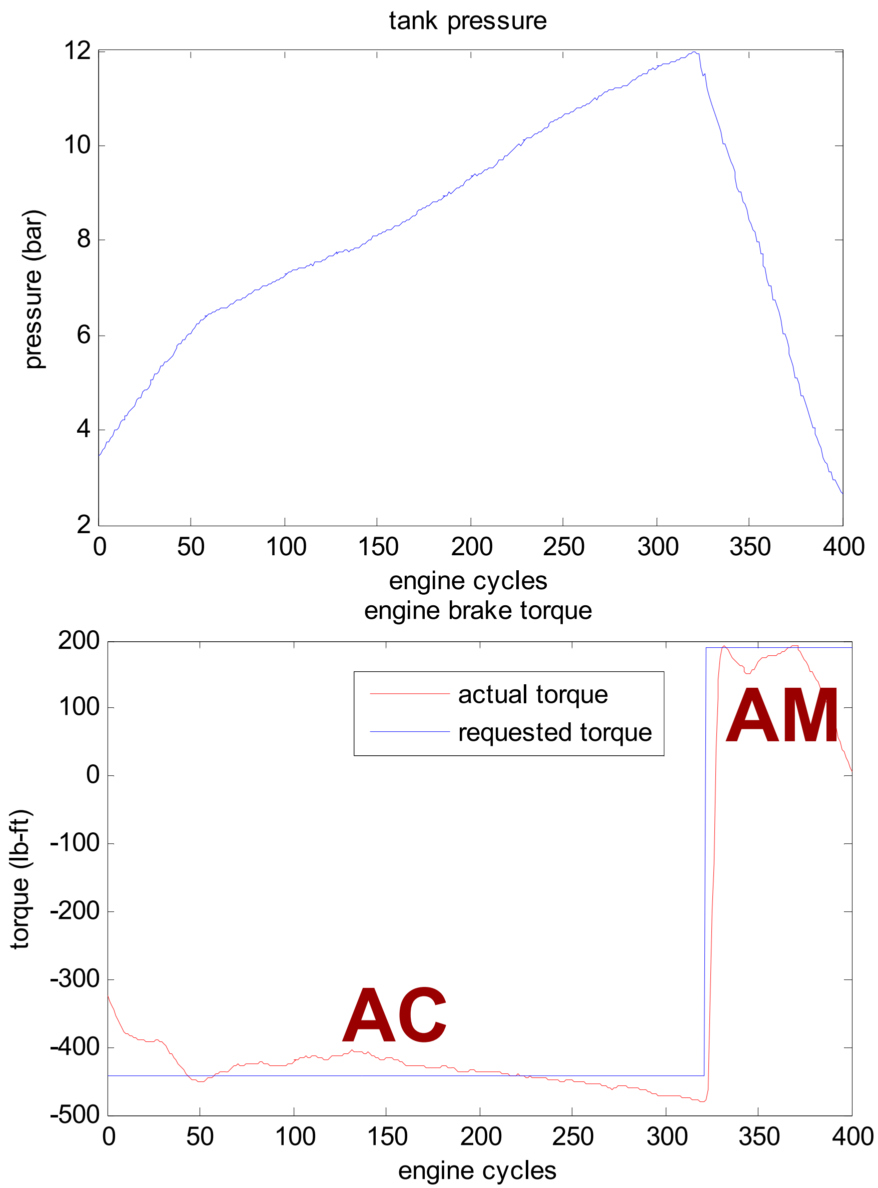




AC Mode: 900rpm, Air Tank Pressure=11bar
Brake Torque=537.3Nm



EVC EVO IVO IVC



AC → AM Mode Switch
900 rpm,
AC requested BMEP
= - 7bar
AM requested BMEP
= 3bar

Next Phase Plan

- Air Hybrid Engine Functionality Test
  - Testing the prototype engine and its sub-systems
  - The test results will be compared to the functional specifications from the deliverables of previous phase.
- Hybrid Engine Control Development
  - To develop and test engine control algorithms for hybrid operational modes.

Summary

- ***Concept evaluation (COMPLETED)***
  - APA technology offers 4 -18% efficiency improvement over a wide range of applications.
- ***APA engine functional specifications (COMPLETED)***
  - Design optimization based on 2nd-law thermodynamic efficiency.
  - CAD/Packaging/Test cell layout.
- ***Engine test***
  - Engine installation was completed.
  - AC, AM mode testing.
  - Debugging Control system

Thank you