True – HEV:

An Innovation for Hybrid Electric Engines

Burzin Balsara and Malav Shah
Clark IRD/LASER

2015-2016

Introduction

- Existing hybrid electric vehicles (HEV) utilize a two component system that is somewhat inefficient in terms of power use and the complex electric and mechanical assembly required
  - Such vehicles mechanically combine two separate systems: a conventional a gasoline reciprocating internal combustion engine (ICE) and an electric motor to provide propulsion for the automobile.
- Frequently, the electric motor is not engaged due to the battery power drain and also because it is sized to provide assistance in acceleration, hill climbing, and other activities to decrease the fuel consumption of the ICE.
- This project proposes a "true" HEV in which the electrical and mechanical propulsion components are integrated in one single hybrid engine. The electrical component which works in a fashion similar to a conventional ICE is designed and implemented in order to prove the feasibility of such an integrated hybrid engine.

Conventional HEV

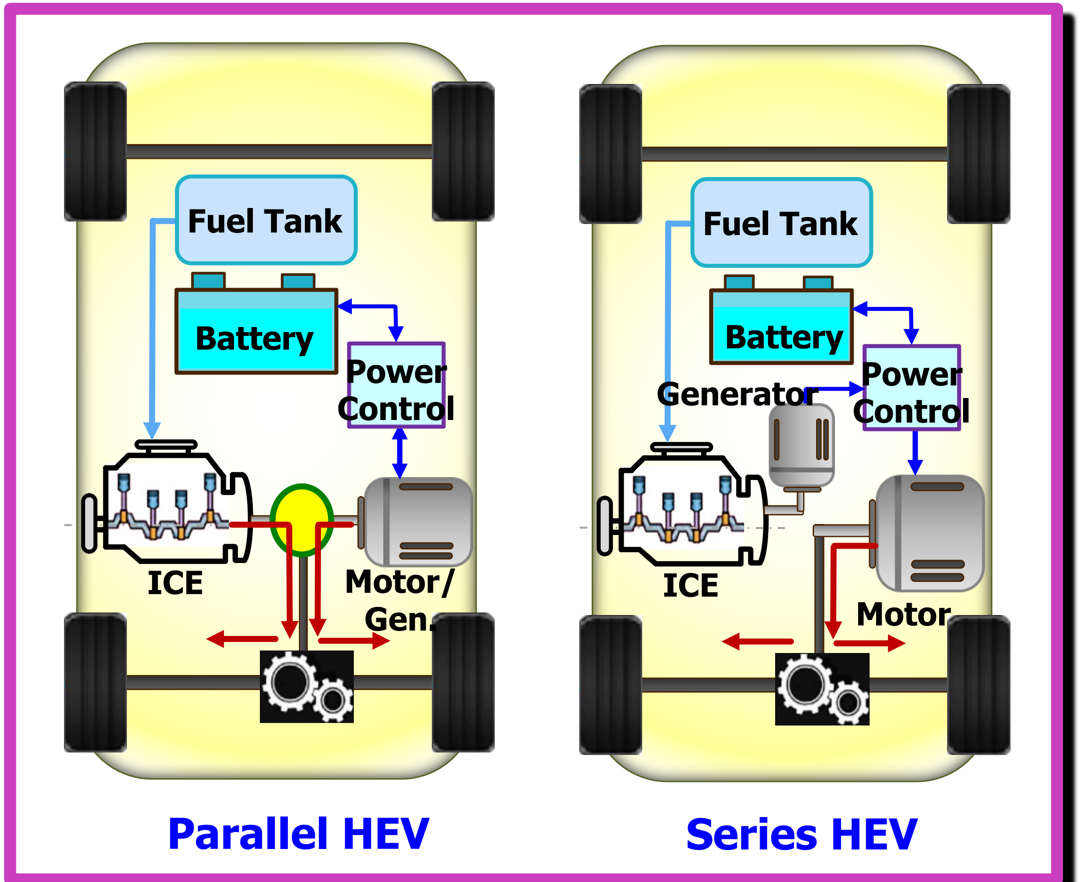


Figure 2: Hybrid electric vehicle (HEV)

Proposed True-HEV

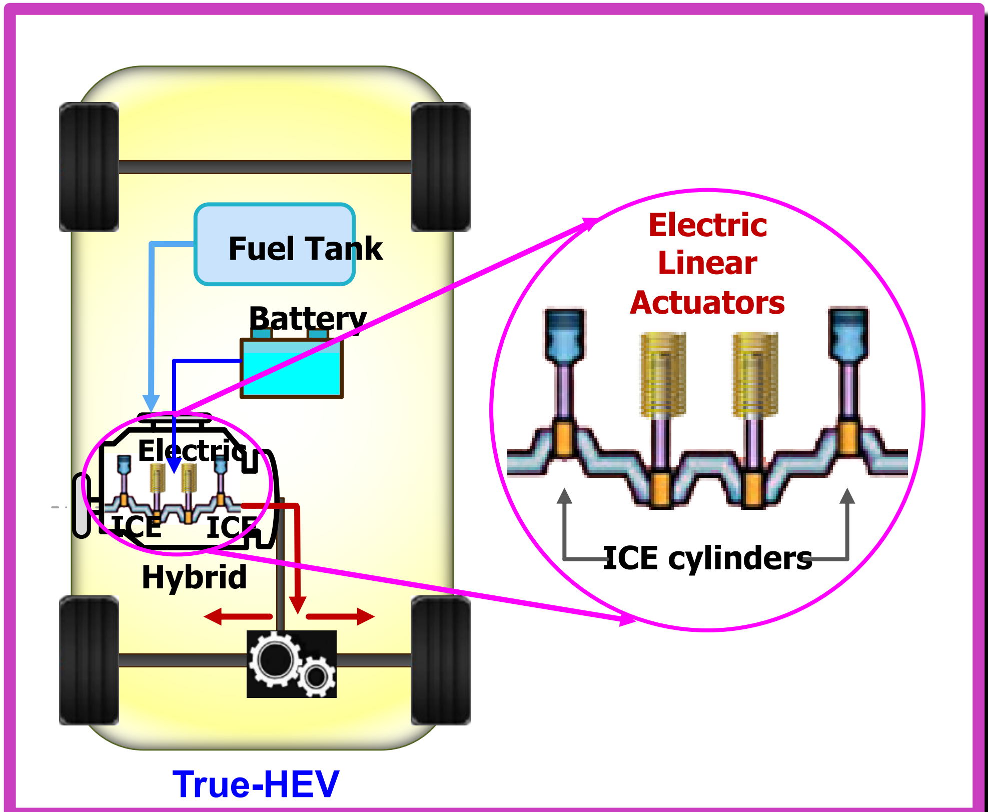
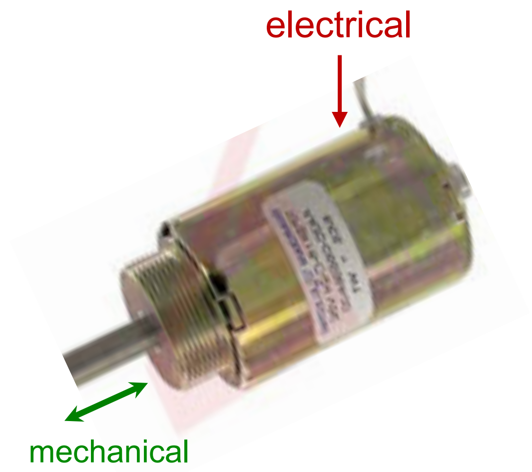


Figure 3: Proposed integrated “true” hybrid engine

Electric Linear Actuators

- Linear actuators, like solenoids, convert electrical energy into linear motion, unlike conventional motors which provide rotary motion
  - Electricity passing through the coil in the solenoid creates a magnetic field, developing electromagnetic force
  - This force produces linear motion by pulling or pushing (unidirectional) or sometimes both (bidirectional) an armature (core)
- In this project, unidirectional solenoids (shown here) were used as linear actuators to provide reciprocating linear motion



Solenoid used in this project

Engineering Goals

- Develop the electrical engine component for a "true" hybrid engine which is compatible with pistons (cylinders) in an ICE such that some of the cylinders of an ICE can be replaced by the electrical system developed here and the rest of the ICE system remains unchanged
- The project goals were achieved specifically through:
    - Engine Movement: The function of the engine should be similar to the conventional internal combustion engine, where reciprocating movement is converted to rotary movement via crankshaft.
        - Utilize 4 independent linear actuators to provide reciprocating (linear) motion needed for a 4-cylinder engine
        - Design and construct a crankshaft to convert linear reciprocating motion to rotary motion
    - Test and characterize the constructed and scaled prototype for metrics such as RPM, voltage, current, and timing signals for solenoids in different configurations
    - Propose a complete True-HEV system to combine the above electric engine with a conventional ICE

Design Specifications

- Mechanical System
  - Build a 4-cylinder scaled prototype engine using 4 linear actuators (solenoids in this project)
  - Construct an appropriate crankshaft for this engine; use different stroke lengths
- Electronics
  - Design an appropriate drive circuit to energize and de-energize the actuators using the low power control signals produced by a microcontroller
  - Drive circuit components should be adequate to provide the necessary power to energize the actuators and appropriate circuitry to rapidly de-energize them
- Control System
  - Use microcontroller (Arduino Uno) to generate actuator control signals in correct sequence, so as to turn the crankshaft without any back and forth oscillations
  - Utilize pulse width modulation technique to vary "on-time" interval for each actuator to vary speed of the overall engine

System Components

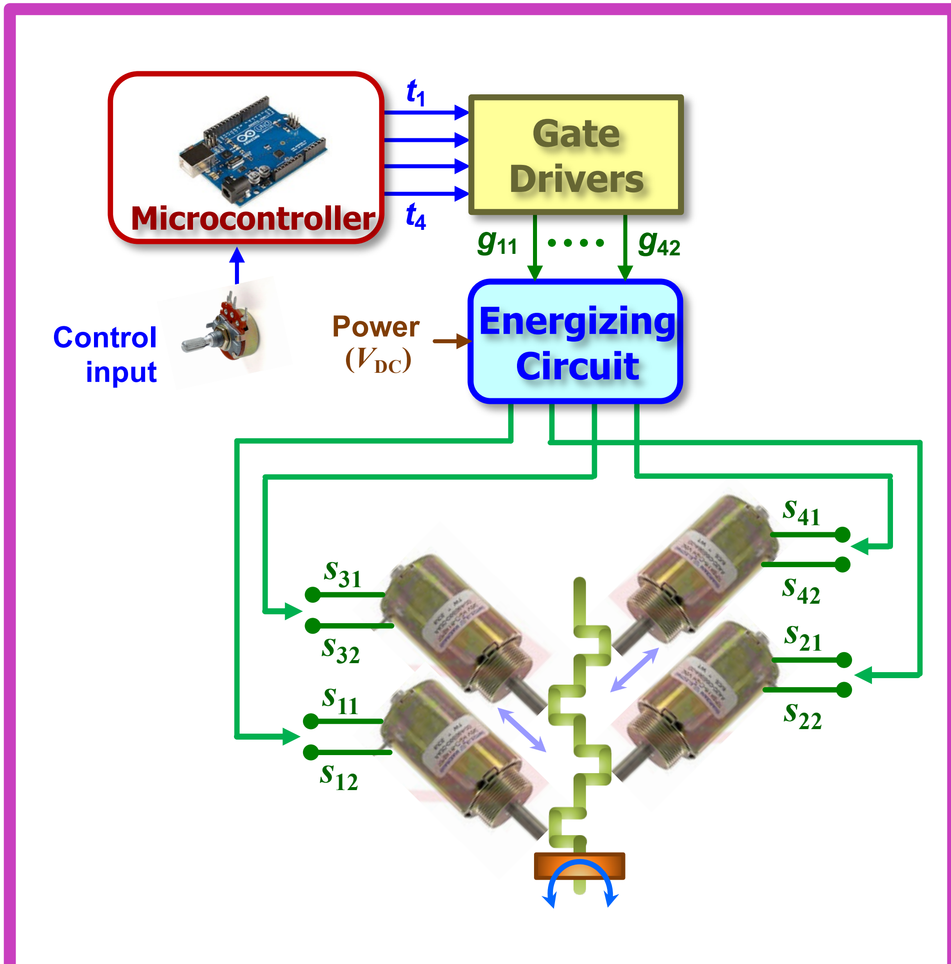


Figure 7: Overall Electromechanical System

Coding

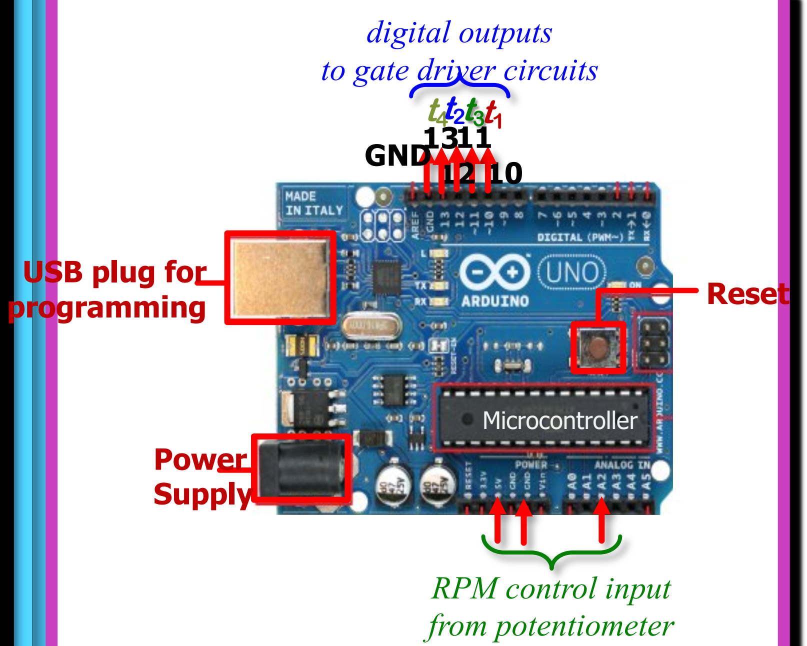
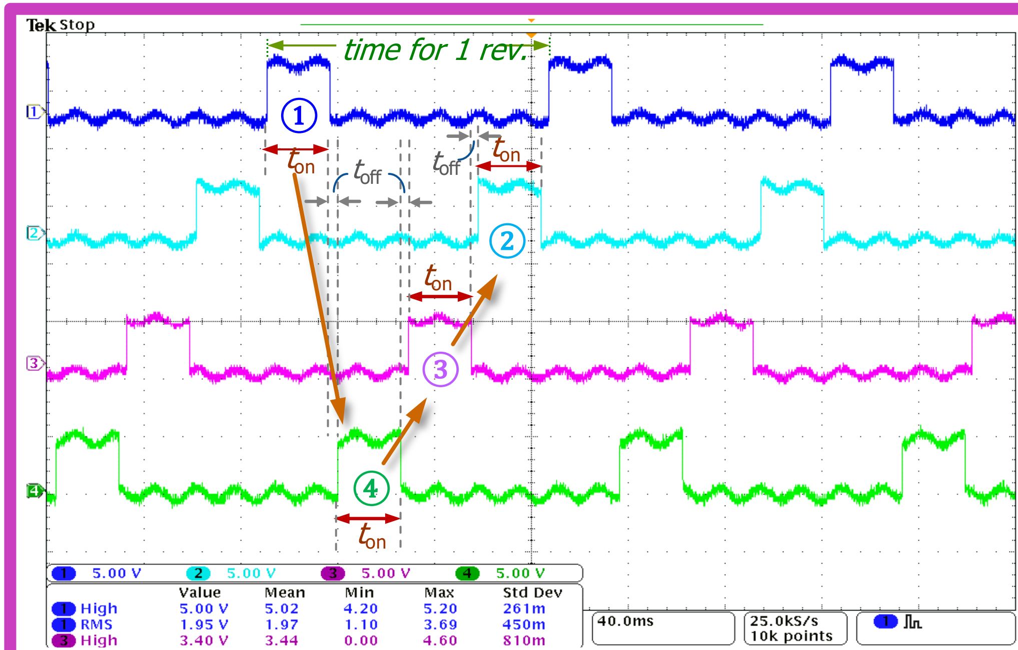


Figure 11: Microcontroller connections



Plot 3: Sequence of control signals from the microcontroller. t_{on} and t_{off} times determine the time taken for one engine revolution.

Energizing Circuit

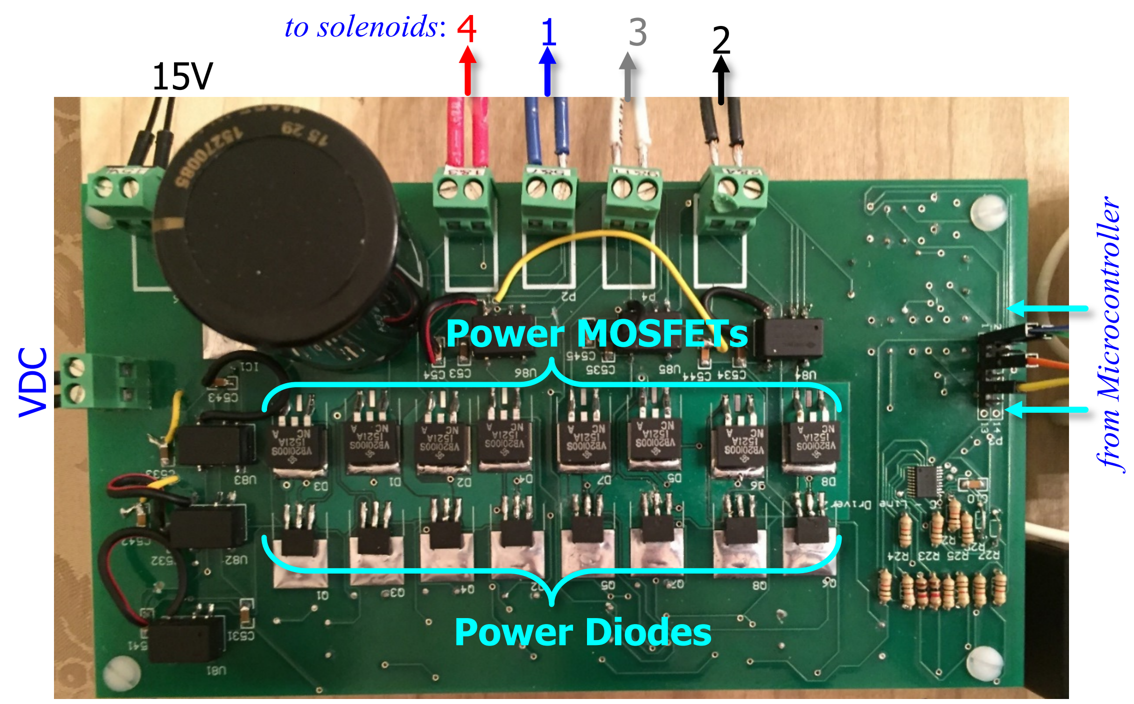


Figure 12: PCB for solenoid driving circuit

Energizing Circuit (Cont.)

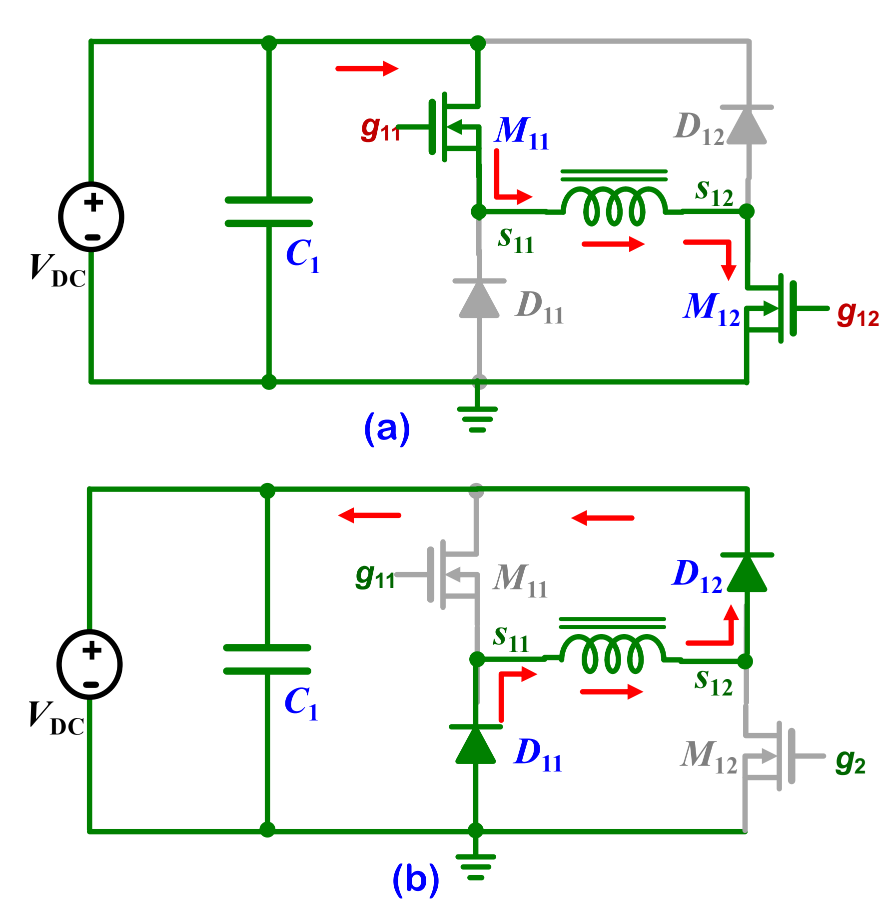


Figure 9: Two operating modes of full bridge ①

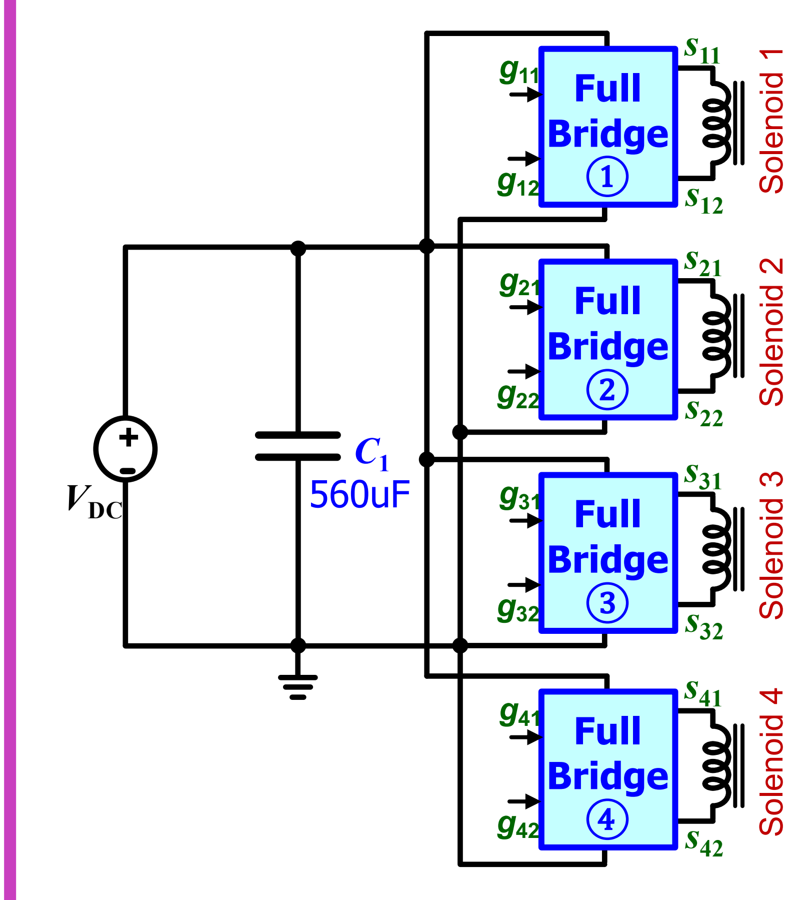
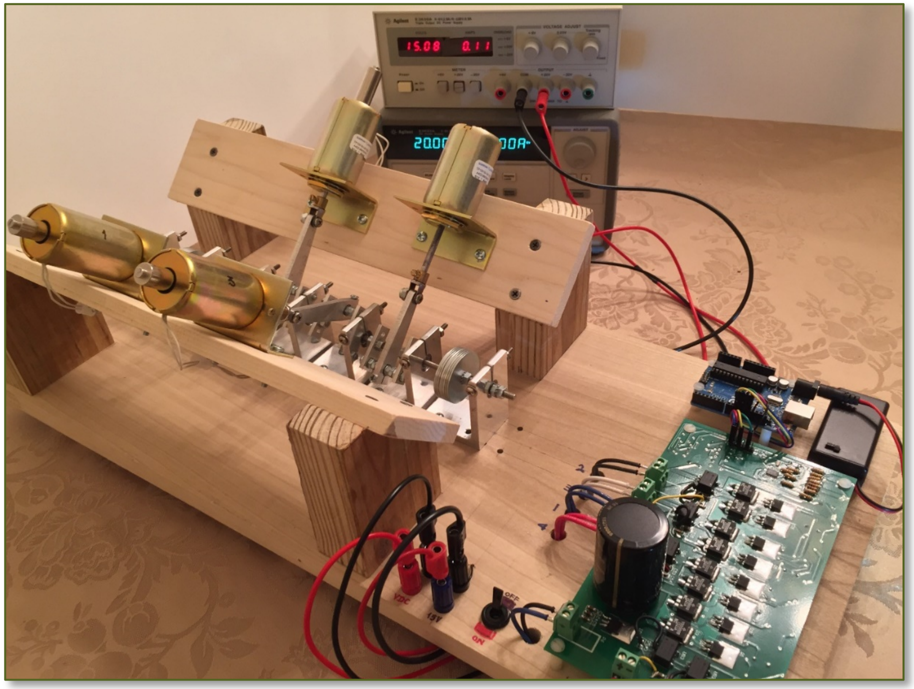
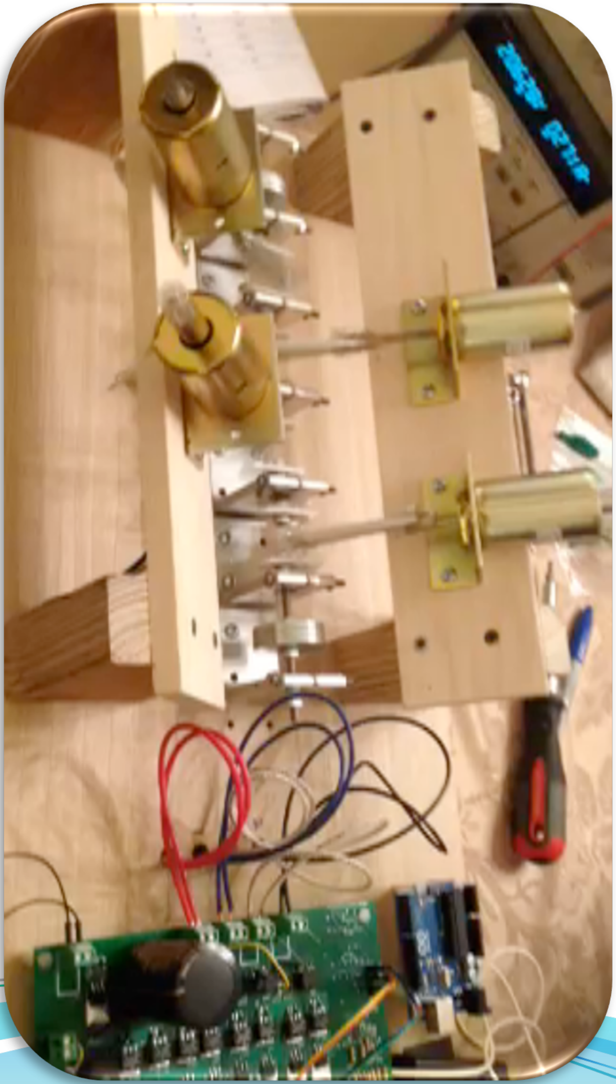


Figure 8: Energizing circuit for the solenoids

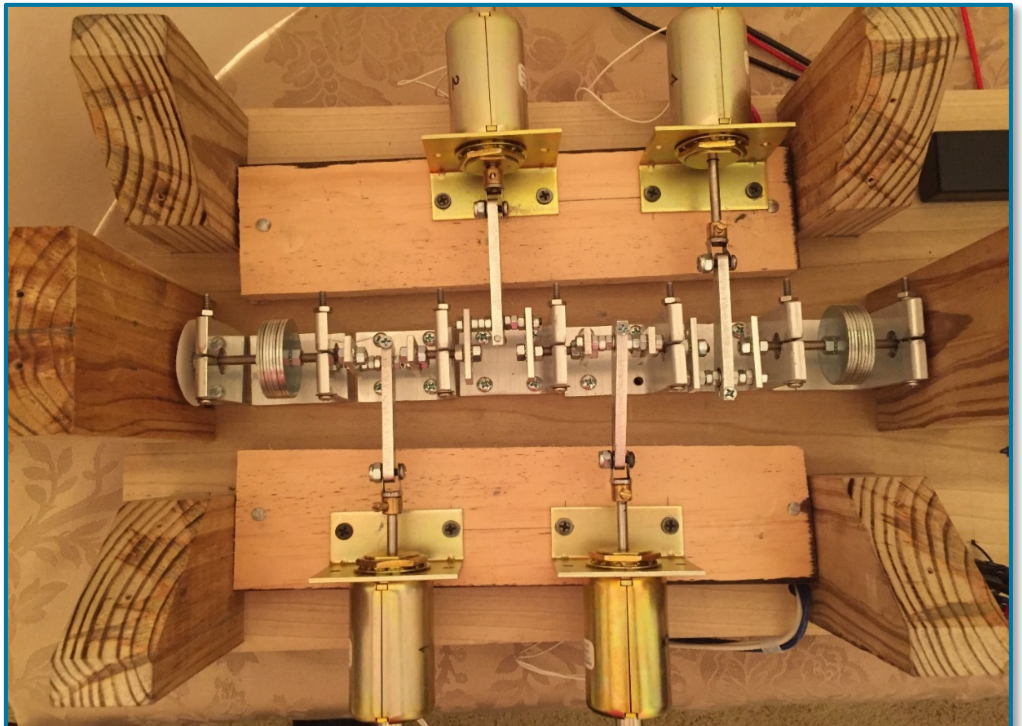
Final Assembly (V4)



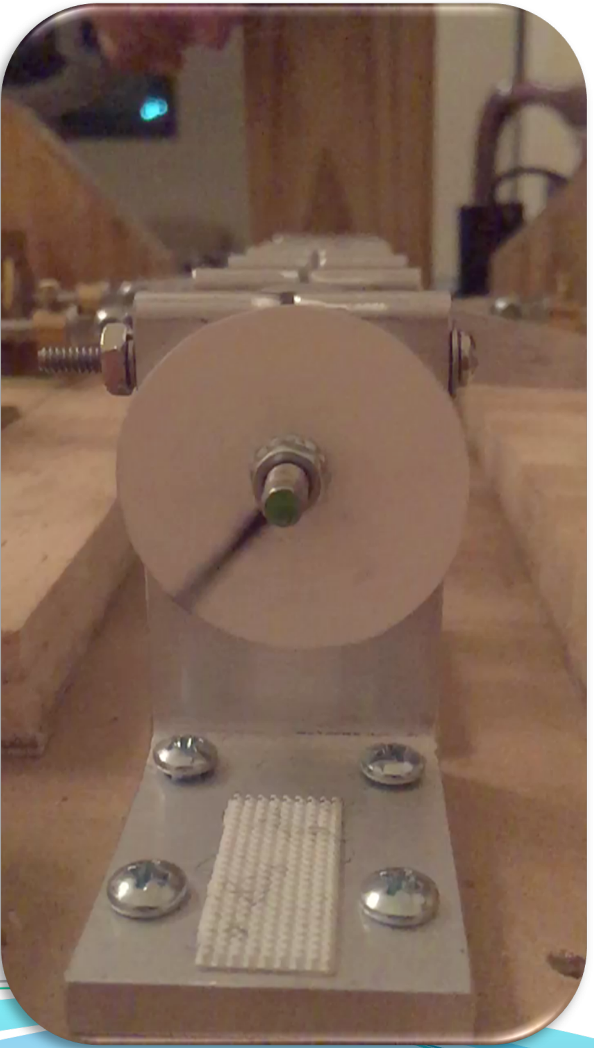
Final setup of V4 Electric Actuator Engine



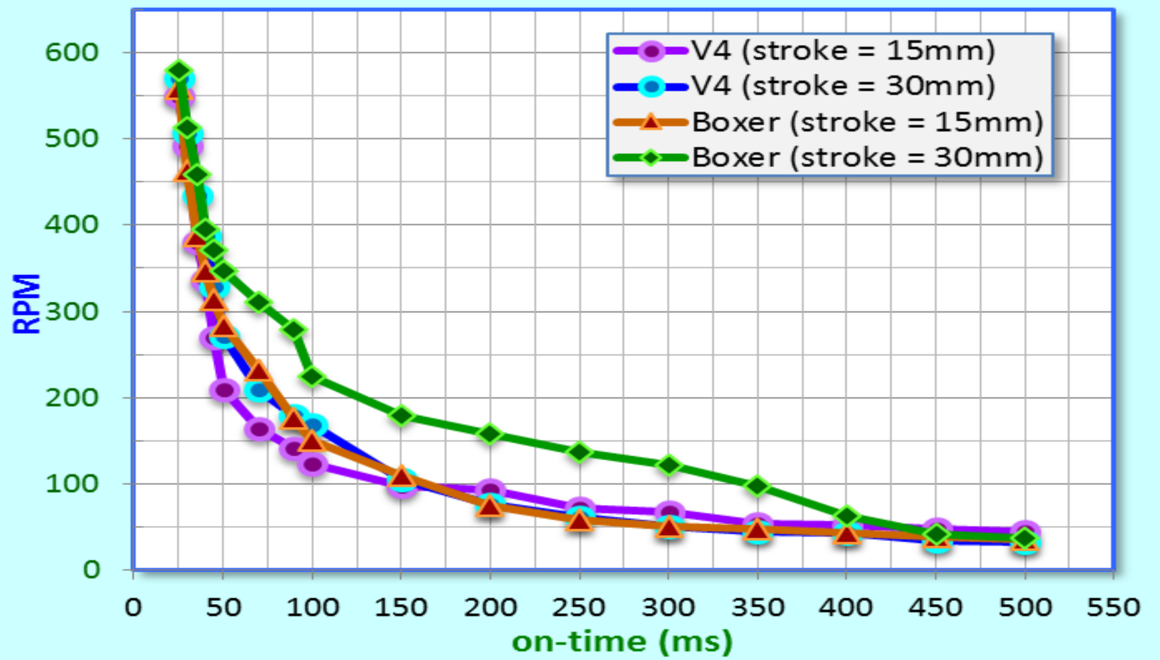
Final Assembly (Boxer)



Final setup of Boxer Electric Actuator Engine



Varying RPM



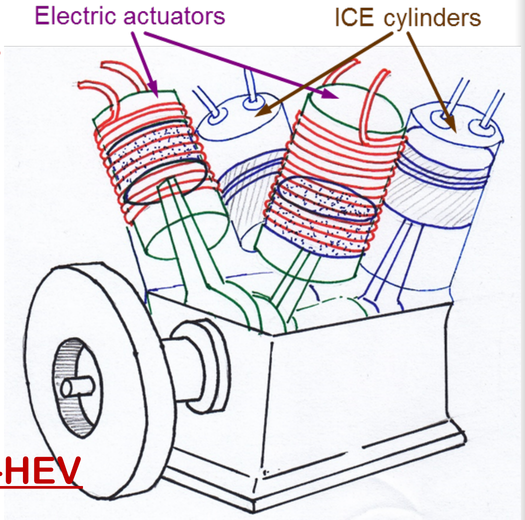
Plot 11: Comparing engine speeds for different engine configurations when on-time, t_{on} was varied to change speed and supply voltage was constant (VDC=20V).

Impact of the Project

- "True" Hybrid Engine system:
  - Electrically energized linear actuators can be used to create an engine similar to the gasoline powered internal combustion engine (ICE) used in automobiles
  - Electrical engine actuators presented here can be integrated with ICE pistons in a single engine chassis using a common crankshaft thus creating a "true" hybrid engine without any complex coupling mechanism as is done in conventional hybrid vehicles
  - Can be built by simply replacing few cylinders in an engine with linear actuators and modifying the electronic ignition system ⇨ cheaper than current HEV
  - Two components of this hybrid engine can be driven by a single electronic drive or ignition system which is modified to handle this "true" hybrid engine. This electronic system can then be controlled by a master microcontroller
  - Linear actuators and ICE pistons can work together or on their own in different ways depending on the engine power needs ⇨ flexibility of control
- Fuel Emissions:
  - Linear actuators do not emit hydrocarbons and carbon monoxide like that in an ICE, hence an all electric engines or partially electric systems are relatively cleaner.

Further Work

- Implementation:
  - Explore other electric actuators like linear switched reluctance motors, which are resilient to high temperature operations
  - Design, implement, and characterize electric actuators based on the torque and speed specifications of IC engines from existing hybrid electric vehicles
  - Implement feedback control mechanism with speed sensors to regulate engine speed
- Proposed True-HEV Design 1: Integrated Hybrid Engine
  - In an existing ICE replace few cylinders by appropriately scaled electric actuators as shown here (2 cylinders are replaced by 2 actuators).
  - Electric actuators and ICE pistons are connected to the same crankshaft ⇨ truly integrated hybrid electric engine.
  - Use a single microcontroller to fire sparkplugs and energize actuators in a correct sequence.
  - Electric actuators also serve as starter motor.



V4 True-HEV

- Proposed True-HEV Design 2: Integrated Hybrid Cylinder
  - Alternatively, electric actuator can be integrated with the ICE cylinder as shown here.
  - A ferromagnetic armature is added to the piston and the stator with its coil can be placed at the end.
  - When the stator coil is energized at the right moment, it pulls in the armature adding to the mechanical force produced by the ICE ⇨ no need for external coupling or gearbox mechanism.
  - When actuator is not used for movement, it can also operate in the generating mode to convert mechanical energy of the ICE to electrical energy.
  - Electrical actuation eliminates the need for a starter motor