Application of Pulsed Detonation Engine for Electric Power Generation

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Acknowledgements: This study is made possible by funding from
Mechanical and Aerospace Engineering Department, UT Arlington and
The National Science Council, Taiwan, ROC
Agenda

- Introduction:
  - Why PDE for Power Generation
  - How PDE can be applied for Power Generation
- Objectives of This Study
- Experimental Setup
- Video of Test Run
- Results
- Conclusion
Advantages of PDE

- Simplicity of design
- Detonation wave does the work of compressing the gas, producing extremely high pressure ratios, higher temperatures.
- No requirement of high compression ratios and thus no compressor required
- Constant volume combustion offers better efficiencies than constant pressure combustion in Brayton cycle
- Better thrust, $I_{sp}$, fuel efficiencies
- Higher weight to thrust ratios

$$Y^a D_a + y_a d^A = YADA$$

$$\therefore$$
PDE Cycle vs. Brayton Cycle

Ψ is static temperature ratio for stoichiometric H2/air system


Second law efficiency

<table>
<thead>
<tr>
<th></th>
<th>$CH_4$</th>
<th>$C_3H_8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>deflagration</td>
<td>27.5%</td>
<td>55.0%</td>
</tr>
<tr>
<td>detonation</td>
<td>38.3%</td>
<td>79.1%</td>
</tr>
</tbody>
</table>
PDE Applications

The attraction of the PDE is its simplicity and versatility

- Mostly military: Missiles, UAVs
- Electric Power Generation: Hybrid PDE with turbine and generator

  - Ground based and Onboard
  - Civilian and Military
  - Large scale and small scale power plants, portable power generators
PDE Hybrid Engines for Power Generation

- A hybrid engine with only 1 PDE operating at low frequency may affect the turbine due to the slow pulsing nature of the exhaust, which also affects the electric power output, creating pulsing noise.
- This can be eliminated by adding a fly-wheel, similar to those on 4 stroke 1 cylinder motor-cycle engines.
- Multiple PDE tubes each operating at a low frequency will smoothen out the exhaust flow.
Many Fuel Options for PDEs

- **Coal**: US DoE estimates that ¼ of world coal resources are in the US, enough to last over 200 years. Efforts are underway to produce clean coal gas.
- **Natural Gas**: US DoE claims that 900 of the next 1000 Electric Power Stations will use Natural Gas. 80% of US Natural Gas is produced internally. LPG, CNG used for vehicles.
- **Propane**: Widely used, available in many container sizes. Imagine a PDE that could take propane canisters.
- **Bio-gas**
- **Hydrogen**: Best and cleanest. Hydrogen economy is set to take off (2020??). Steps are underway to produce H₂ from hydrocarbon fuels, e.g., Natural Gas, coal, etc.
- **Coal aerosol??**
- **Kerosene**
- **Jet Fuels**
- **Octane**

PDEs can be designed to operate on virtually any fuel. It just takes a little bit more engineering.
PDE and Pulse Jets for the Masses

• There is a growing interest among amateurs and hobbyists and small time entrepreneurs into PDEs, Pulse jets, Turbo-charger jets

• Kits available on Ebay and online stores

• One of the best sites: Bruce Simpson T/A FAB Jets
  http://www.aardvark.co.nz/pjet/links.htm

Wider interest will fuel innovation and funding driven by market forces
Objectives of This Study

- To assemble a proof of concept working model of a hybrid PDE-turbine-generator system
- Use commonly available fuels
- Low budget
- To identify possible problems in the implementation of a PDE-turbine-generator system
Experimental Setup

Diagram:
- Gas Injection through Solenoid Valves
- 10 inch Internally Grooved Spiral Section, Water Cooled
- 8 Channels
- 4:1 Voltage Divider for DAQ
- Bicycle Head Lamp: 1.8 Ohm
- Speed Reduction wheels in contact
- AC Generator
- Cold Air Inlet
- Compressed Air Outlet
- Turbocharger
- Type K Thermocouple
- Blow Down Section with embedded Pressure Transducers
- Exhaust Outlet
- Differential Pressure Transducer
PDE

I.d. of tube is 3/4 in.

9-Mar-07

AERODYNAMIC RESEARCH CENTER
MECHANICAL AND AEROSPACE ENGINEERING DEPARTMENT
Electronically Controlled Gaseous Injectors

Solenoid Valves
• 12 Vdc, 8A peak, 2A hold.
• Fast acting (2ms reaction time). Up to 35Hz tested successfully. 50Hz max.
• Easy and precise control possible using TTL signals from a remote computer.
• Max pressure 550 kPa (90psig)

AFS-Gs60-05-5c series Fuel Valves
Ignition System

150 mJ max energy per spark Inductive Ignition System

A transistor control circuit built in house enables the interfacing of the ignition system to the DAQ PC and allows ignition to be controlled remotely using TTL signals.
Turbo-Charger

- AG Kühne, Kopp & Kausch in Frankenthal, Germany (1899)
- Schwitzer Company in Indianapolis, Indiana (1918)
- BorgWarner Automotive (Auburn Hills, Michigan) took over 3K in 1997
- BorgWarner Automotive took over Schwitzer Co. in 1999
- BorgWarner Turbo Systems is headquartered in Kirchheimbolanden, Germany
- Supplies turbo-chargers to commercial and passenger engine and automobile manufacturers from Alfa Romeo to Caterpillar to Cummins to Porsche to VW

The compressor can deliver a maximum air flow rate of 0.17 kg/s. Recommended for automotive engines of up to 150 kW power rating.

The turbine’s inlet is 40 mm in diameter; and the outlet is 65 mm in dia.

The compressor’s inlet is 36 mm, and the outlet is 38 mm in dia.

The turbine is capable of withstanding temperatures as high as 1050°C and running at up to 200,000 rpm.

Used in Volkswagen Passat 1.8T and Audi A4/A6 1.8T model cars, which have 5 valve 4 cylinder gasoline engines.
• Oil supplied by an oil pump from an old Dodge truck, turned by an electric motor so that oil pressure is maintained at 40 to 60 psi
• Water supplied at tap pressure

Turbine over-pressure trap door was bolted shut
Bicycle Dynamo Generator

Motor ↔ Generator

Motors are run at 1000 to 10,000 rpm

Small DC motors used in RC Cars run at 18,000 rpm, but they are too small and rated for lower power.

Rated at $6V_{\text{RMS}}$, 3W @ ~2000 rpm

Powers

- a bicycle headlamp (1.6 $\Omega$, 22.5 W)
- and
- a red tail lamp (8.7 $\Omega$, 4W)

www.myra-simon.com/bike/dynamos.html
bicycle bottle dynamo

Brushless ac generator
2 pole permanent magnet rotor
Wire wound stator armature
dc resistance of 4.2 Ω

The magnitude of the voltage output is proportional to the strength of the magnet, the number of turns in the windings and the speed of rotation of the rotor.

\[ N_D = \frac{120f}{p} = \frac{120f}{2} = 60f \]

\( N_D \) is the rotational speed of the dynamo rotor in rpm

\( f \) is the frequency of the ac voltage in Hz

\( p \) is the number of pairs of poles.

Neglecting slip, speed of turbine is \( N_T \)

\[ N_T = N_D \cdot \frac{1.85\text{in.}}{0.56\text{in.}} = N_D \cdot 3.3 \]
Generator output is connected in parallel to the bicycle headlamp (1.6, 22.5 W) and the red tail lamp (8.7, 4W) the DAQ through a 4:1 voltage divider. The total parallel resistance $R_{\parallel}$ is 1.351 Ω.

The lamps are considered to be purely resistive loads for simplicity.

\[ I_{RMS} = \frac{V_{RMS}}{R_{\parallel}} = \frac{V_{RMS}}{1.351 \Omega} \]

\[ P = \frac{V_{RMS}^2}{R_{\parallel}} = \frac{V_{RMS}^2}{1.351 \Omega} \]

$I_{RMS}$ is the RMS current

$V_{RMS}$ is the RMS voltage

$P$ is the power output.
### Results of 15 Hz test Propane-Oxygen

#### Graph showing Generator Output Volts vs Absolute Time (hr:min:sec)

<table>
<thead>
<tr>
<th>Time (h:m)</th>
<th>Time (s)</th>
<th>Peak Voltage</th>
<th>V&lt;sub&gt;RMS&lt;/sub&gt;</th>
<th>Freq. of Output (Hz)</th>
<th>Power (W)</th>
<th>Generator Speed (rpm)</th>
<th>Turbo Speed (rpm)</th>
<th>Compressor Flow Rate (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19:59</td>
<td>10.6562</td>
<td>5.7</td>
<td>4.03</td>
<td>225.124</td>
<td>12.02</td>
<td>13,507</td>
<td>44,575</td>
<td>0.0464</td>
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<tr>
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<td>11.6562</td>
<td>8.41</td>
<td>5.95</td>
<td>621.922</td>
<td>26.18</td>
<td>37,315</td>
<td>123,141</td>
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<td>19:59</td>
<td>15.3906</td>
<td>8.42</td>
<td>5.95</td>
<td>641.491</td>
<td>26.24</td>
<td>38,489</td>
<td>127,015</td>
<td>0.0539</td>
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<td>16.3902</td>
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<td>5.90</td>
<td>600.519</td>
<td>25.74</td>
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<td>21.9219</td>
<td>8.11</td>
<td>5.73</td>
<td>501.458</td>
<td>24.34</td>
<td>30,087</td>
<td>99,289</td>
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<td>5.66</td>
<td>484.447</td>
<td>23.75</td>
<td>29,067</td>
<td>95,921</td>
<td>0.0516</td>
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9-Mar-07
Results

- Propane + Oxygen at equivalence ratio of 1.2, 0.0057 kg/s
- Exhaust of Turbine is at 800°C
- Turbine spins at over 127,000 rpm
- Compressor outputs air flow of over 0.055kg/s
- Detonation observed in PDE
- No damage visible in turbine after over 1 minute of run time
Conclusions and Recommendations

- A PDE-turbine-generator system successfully tested.
- Generator produces about 26 W of power, while Compressor pumped air at 0.055 kg/s at turbine speeds higher than 127,000 rpm.
- Exhaust temperature of turbine is 800°C, suggesting that there was enough enthalpy in the flow to drive another turbine stage.
- One PDE tube at 15 Hz drove the turbine at a significantly high speed, as the PDE exhaust velocity is high, as opposed to the exhaust of automobiles.
- The turbine’s rated 200,000 rpm could be achieved by running the PDE at higher speeds.
Conclusion and Recommendations (contd.)

- Radial turbines create high losses, as flow is turned 90°, suffer high temperature and pressure effects of high speed flows.
- The turbine and generator has to be matched in terms of speed, torque, power output.
- Transmission (with speed reduction for generator) has to be robust and capable of harmonizing the speed and torque of turbine and generator.
- Noise of PDE has to be dealt with.