A Study of Bi Stable Gas Exchange in Two Stroke Engines

Jason Papadakis
Verification & Analysis
Introduction and Motivation

- Legislation, Consumers and Manufacturers are continually seeking the following vehicle improvements:
  - Better Fuel Economy
  - Lower Emissions
  - Better Performance
  - Lower Cost

- These ongoing demands will intensify
Bi Stable Gas Exchange in Two Stroke Engines

Introduction and Motivation

- Much of the focus falls on the engine performance though this may reduce consumption only so far

- Examining the vehicle itself to find the actual energy of transportation below in a C Segment vehicle over the WLTP3

EU 2020 NEDC Target (g/km)

CO2 Emission vs Powertrain Efficiency

- CO2 Over Cycle (9.99% Efficiency)
- CO2 Over Cycle (33% Efficiency)
- CO2 Over Cycle (99% Efficiency)
Future Technology Paths

Future Gasoline Engine Technologies

- Range Extenders and Hybridization
  - Low cost
  - Compact
  - Lightweight
  - Reliable

- Downsizing
  - High boost
  - Advanced combustion
  - High specific loading
  - Mild electrification

- Downsizing with Additional Measures
  - High boosting and charge-cooling requirements
  - Lean combustion or EGR
  - Variable CR, Valvetrain
  - Mild electrification

Future Technology Paths

Gasoline Spark Ignition Downsizing Today

- Electrification
- Downsizing
- Further Downsizing + Additional Measures

Bi Stable Gas Exchange in Two Stroke Engines
Bi Stable Gas Exchange in Two Stroke Engines

The Two-Stroke Engine in a Modern Vehicle

- Even given the historical view of the two stroke engine there are some potential benefits of its use in modern vehicles
  - High power density therefore physically small and lightweight
  - Can be run Naturally aspirated as well as Turbocharged
    - Negates the need for costly boosting systems
  - No need for over fuelling while running at high loads

- Ricardo 2/4SIGHT
- Renault POWERFUL 2 Stroke Uniflow Scavenged Diesel Engine

- This is not to say that there are no challenges
  - Emissions
    - Combustion of lubrication oil – Particulate Filters are becoming commonplace to capture soot
  - Load Control - The two stroke cycle is prone to misfire at part load
    - This is a documented phenomena that can be studied using GT-POWER

Bi Stable Gas Exchange in Two Stroke Engines

Definition of the Problem: Misfire at Part Load

- Two Stroke Gas Exchange has no discrete strokes – Permanent Overlap – IEGR Mixing
  - As intake pressure decreases either as we seek to reduce engine output or engine speed increases at a constant throttle position we transition from firing to misfiring

Change in Intake Pressure 3000 RPM

![Graph showing change in BMEP (Brake Mean Effective Pressure) with time for different intake pressures at 3000 RPM.](image-url)
The models are a two cylinder “Boost Only” intake and a single cylinder crank case scavenged - This phenomena will present in both externally scavenged as well as crank case scavenged engines

This leads to an operating map like the below, where although the engine may be producing a positive net BMEP, it is misfiring periodically below the Minimum Stable Load

![Graph showing BMEP vs Engine Speed]

- **Stable Region**
- **Unstable Region**
Bi Stable Gas Exchange in Two Stroke Engines

GT-POWER Model Setup

- The Engines scavenging performance is defined by a curve that describes the efficiency of the intake ports in expelling burned gas from the exhaust port without mixing the two.
  - Necessary because all gas exchange occurs with overlap at BDC (Full Cylinder Volume) commonly used Perfect Mixing assumption (used at TDC overlap) is not valid here.

- EVO 97°CA ATDC
- IVO 120° CA ATDC
- Blowdown 23° CA
- Crankcase CR 1.5:1
- Geometric CR 10:1
- 10-90 Duration 30° CA
- 50% Burn Point 10° CA
- #2 10-90 Duration 30° CA
- #2 50% Burn Point 80° CA
- Fuel: 95 RON Gasoline
- AFR 14.7:1 Direct Injection
Gas Exchange occurs at BDC at Overlap, the burn profile has a significant effect on the flow through the exhaust port as well as the flow through the Transfer Ports (Intake)

- The Blowdown period is the time available for exhaust gasses to leave the cylinder before the transfer ports open
- As engine speed increases at a steady intake pressure, pressure in the crank case reduces and time for blowdown to occur reduces
Sensing the trapped residuals leads to the decision as to how the following cycle will behave

- Based in IEGR%
Lu et al. have performed a study supported by engine testing where it was found that misfire occurrence predicted by checking the condition $Q_{loss} > Q_{comb}$, is equivalent to predicting that if IEGR exceeds 30%, misfire will occur

- where $Q_{loss}$ is the heat lost from the initial flame kernel and $Q_{comb}$ is the heat released in the flame kernel

This is implemented in GT-POWER as two different combustion profiles based on work from Ohira et al. and allows the following to be replicated in Simulation
Bi Stable Gas Exchange in Two Stroke Engines

GT-POWER – Transfer Port Geometry

Upsweep Angle

- Work from Sharma et al. shows that the combustion stability can be influenced by altering the geometry of the transfer ports to scavenge the area around the spark plug
  - While stability improved, unburnt hydrocarbon emissions increased
  - Work at MAHLE Powertrain UK suggests that increasing the upsweep angle ($\alpha$) of the transfer ports can scavenge the spark plug area – Also increases HC emissions at full load

- Question: Can varying the transfer port duration ($\beta$) improve stability?

- Changes to the Transfer port duration change the port area – change port velocity
- For this case we are able to maintain the same port area and secondary compression ratio
- Compare to 4mm Throttle diameter Baseline
Bi Stable Gas Exchange in Two Stroke Engines

GT-POWER – Transfer Port Geometry

Duration

- The nominal Duration is 118°CA
  - Port configuration - extends to BDC, symmetrical around BDC
  - Ports of less or greater duration are effectively “wider” or “narrower” in the cylinder to maintain the same Time-Area during the cycle

- It is difficult to conclude about changes to the scavenging from the cyclic BMEP so if we examine the mass flux across the transfer port boundary

- It is easy to see the difference when considering the mass flow

- Care is required to ensure mixing of fresh and burnt mass is accounted for in the transfer port and crank case!
There are existing systems in production today that offer a variable geometry or variable duration exhaust port.

The effect of this would be to increase the blowdown time to reduce backflow into the transfer port and crankcase.

The drawback of this is that we are reducing the length of the expansion stroke and hence reducing the thermal efficiency.

As before it is difficult to judge improvement from the variation of BMEP over time.

It is possible to see a decrease in BMEP for the longer duration exhaust port.
Bi Stable Gas Exchange in Two Stroke Engines

GT-POWER – Exhaust Port Geometry

Duration

- It is possible to see differences in the mass flow rates through the transfer ports when the exhaust port duration is changed.

- From this we can see that changing the exhaust port duration in a Schneurle loop scavenged Two Stroke engine has multiple effects on the cycle.

- Further investigation is required here to obtain solid conclusions on the exact effects of a port duration change.

Cylinder Trapped Mass

- Long +8°CA — Nominal Duration — Short -8°CA

Mass [g]

Crank Angle [deg]

BDC

INTAKE/COMPR.

TDCF

POWER/EXHAUST

180

BDC

-180

0

180
Further Work and Conclusions

- Through this work we have demonstrated an approach to modelling part load misfire
- We have also shown that the model is sensitive to engine parameters such as port duration and throttle position

- Undertake a statistical approach to analysing the results
- Moving Geometry CFD for Different port geometries
  - Scavenging objects will change
- Estimate/determine if different burn profiles are required for different port geometries
  - Different charge motion may influence burn rate and tolerance of high IEGR%
Many Thanks to Gamma Technologies for Organizing this Conference

Thank you for your attention!

And Many Thanks to friends MAHLE Powertrain for their supporting
Bi Stable Gas Exchange in Two Stroke Engines

References

- GT-POWER Flow Theory Manual
- Books by Gordon Jennings