Extending Exhaust Gas Recirculation Limits in Diesel Engines

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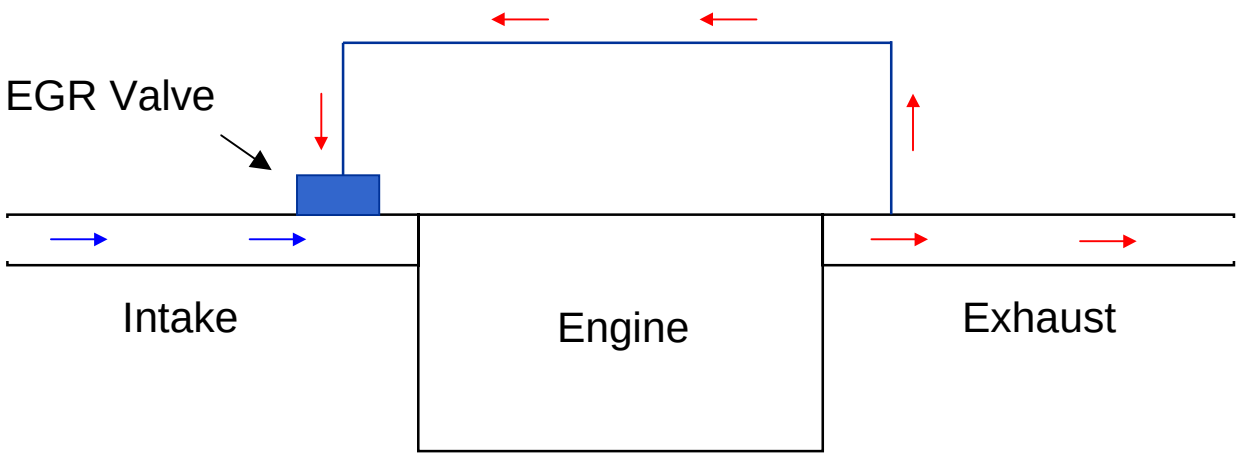
Overview

- Objective and Approach
- Experimental Setup
- Results
- Control Concept
- Virtual Sensor
- Summary and Conclusions
- Future Plans

What is Exhaust Gas Recirculation (EGR)?

- Exhaust gas is mixed with incoming air before being inducted into the combustion chamber.
- Used in light duty engines to reduce NO_x by reducing flame temperature.
- Engines are typically operated below their maximum EGR potential.



Project Focus

Objective

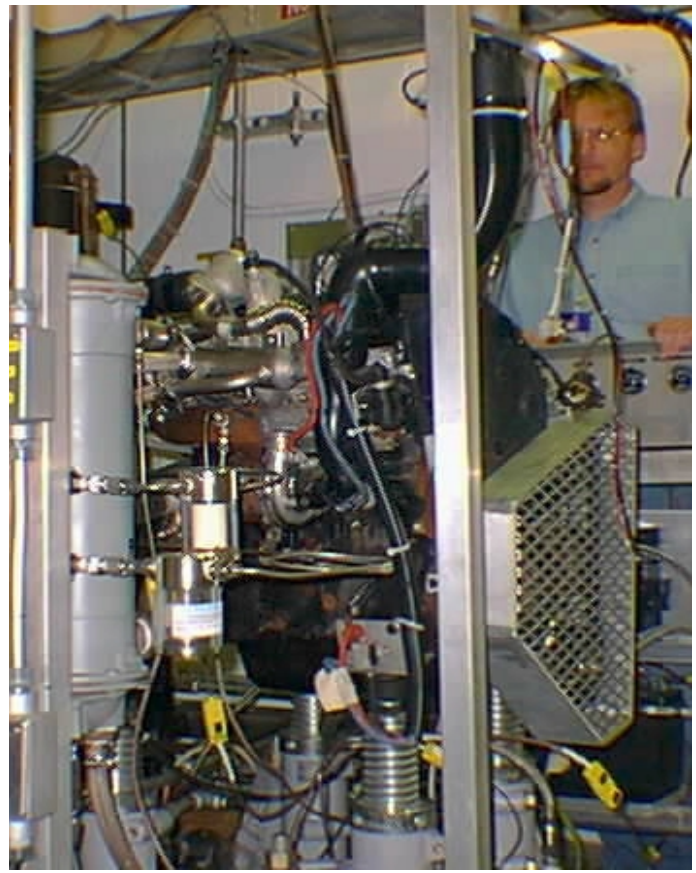
- Develop options for extending EGR limits to reduce NO_x while maintaining hydrocarbon and PM emissions – Extending EGR limits with stable combustion can reduce engine-out NO_x.

Challenges

- Combustion instability (combustion variations resulting in unacceptable emissions).
- Cycle-to-cycle and cylinder-to-cylinder variations in F/A ratio, mixing, and EGR.
- Impact of system parameters (e.g., EGR manifold design) poorly understood.

Experiments performed on a modern automotive diesel engine

- 1.9-L VW turbocharged 4-cylinder, unit injection.
- Test-stand mounted with eddy-current dynamometer.
- Independent EGR adjustment.
- 4-cylinder pressure measurement.
- Regulated emissions measurements.
- Special measurements:
  - Cambustion fast FID (HC)
  - LBNL scatterometer (PM)
  - TEOM accumulator (PM)
  - SMPS (PM)



Special measurements ….

- Fast HC Concentration

  Fast FID measures HC concentration with 4 ms time resolution.

- Particle Mass Concentration

  Tapered Element Oscillating Microbalance (TEOM) measures particulate mass concentration and total mass accumulation with 3 sec resolution.

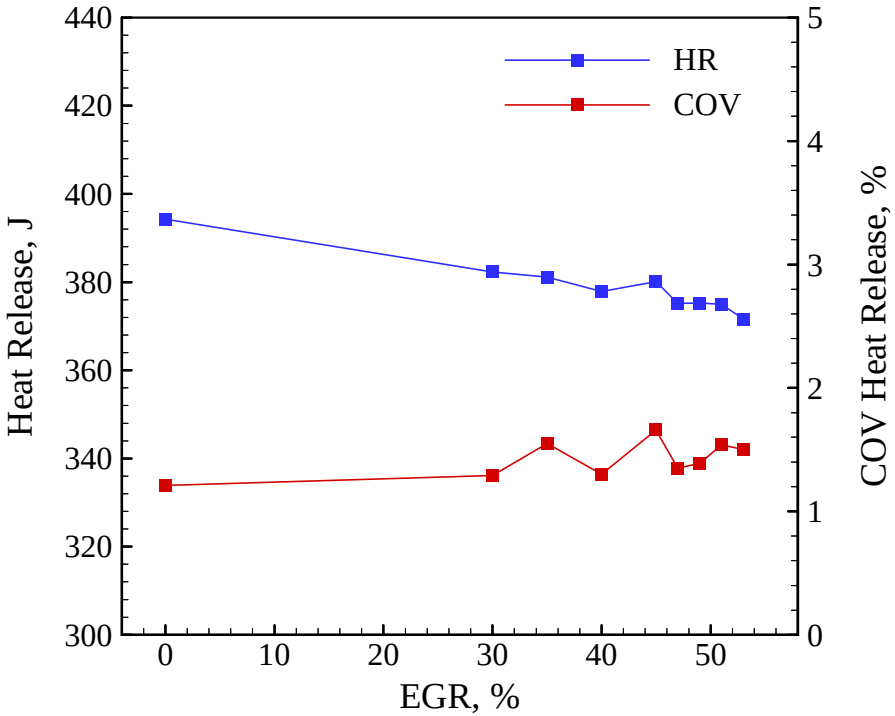
- Particle Size Distribution

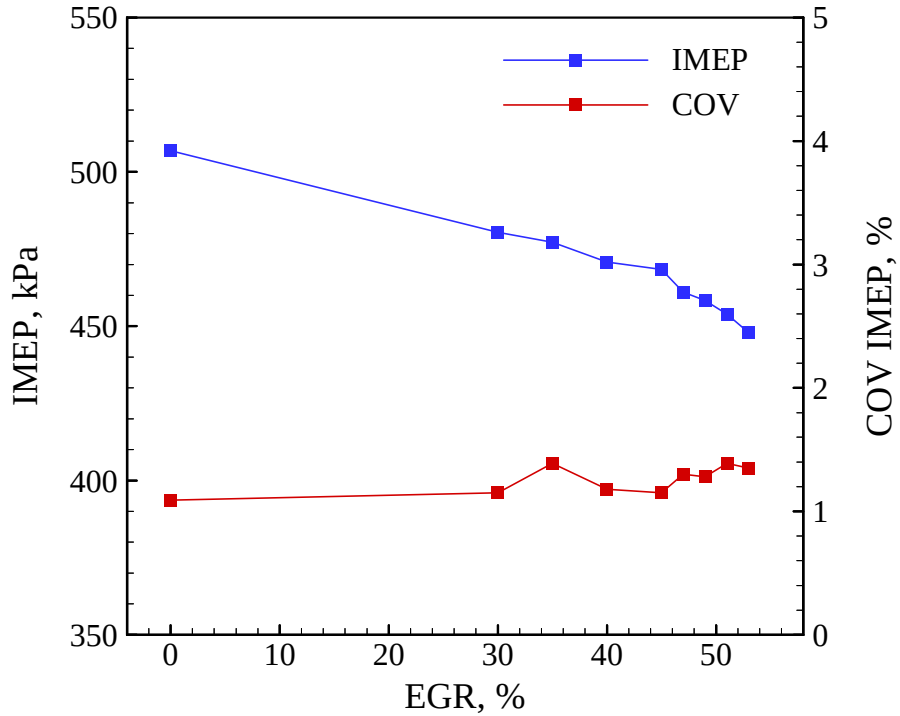
  Scanning Mobility Particle Sizer (SMPS) measures steady state size distribution. Range set at 11 nm - 505 nm.

- Rapid Particulate Mass Emissions

  Diesel Particle Scatterometer (DPS) functions as a fast “smoke” or particle “density” meter. Exhaust sample taken directly from exhaust manifold. Developed in collaboration with LBNL.

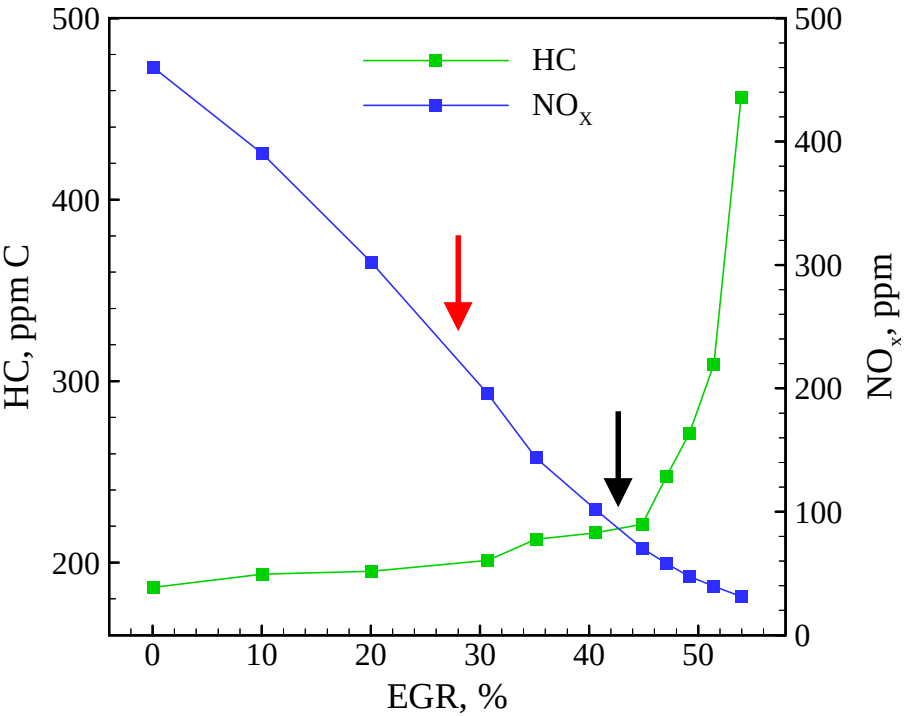
EGR has only small effect on “roughness”

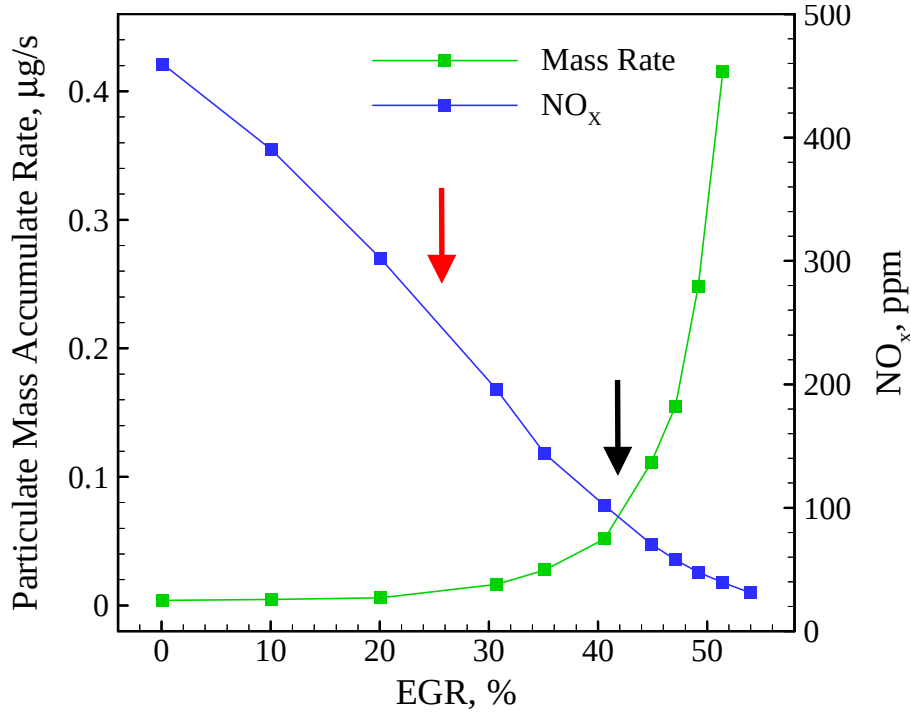




COV of the integrated combustion parameters is within accepted driveability limits for all EGR levels.

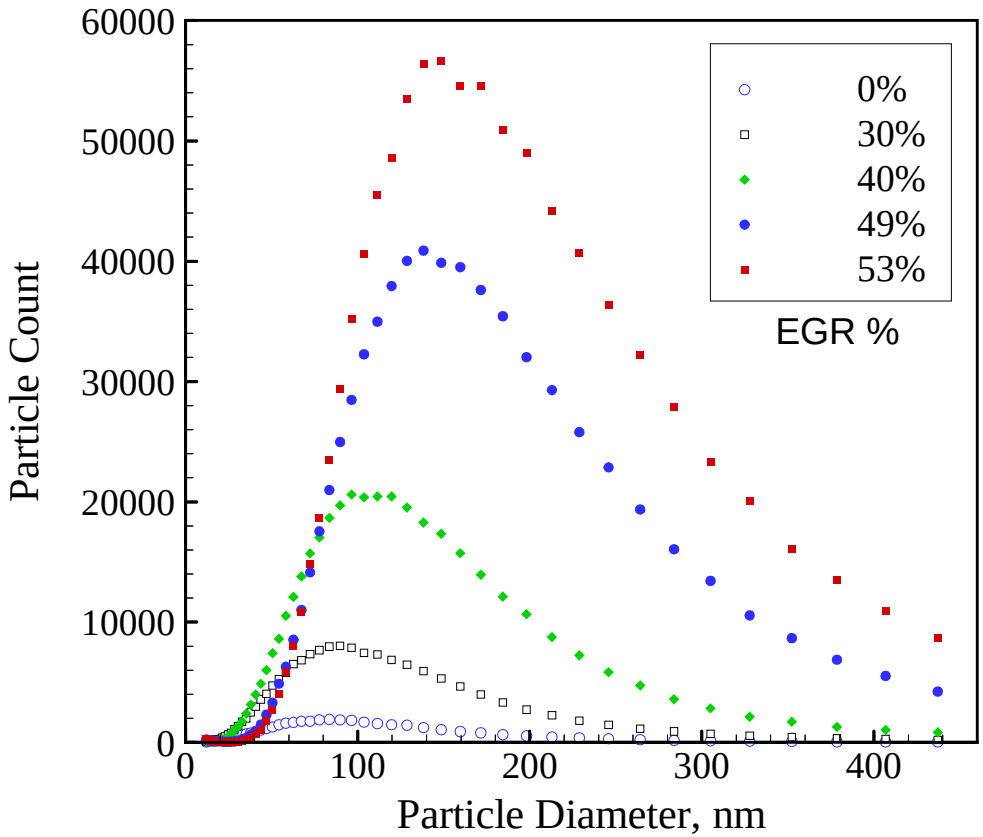
Ultimate EGR limit is delineated by a sudden increase HC and PM





Sharp transition is in contrast to slight changes observed in combustion parameters (shift in combustion chemistry).

Particle count and size increase with EGR



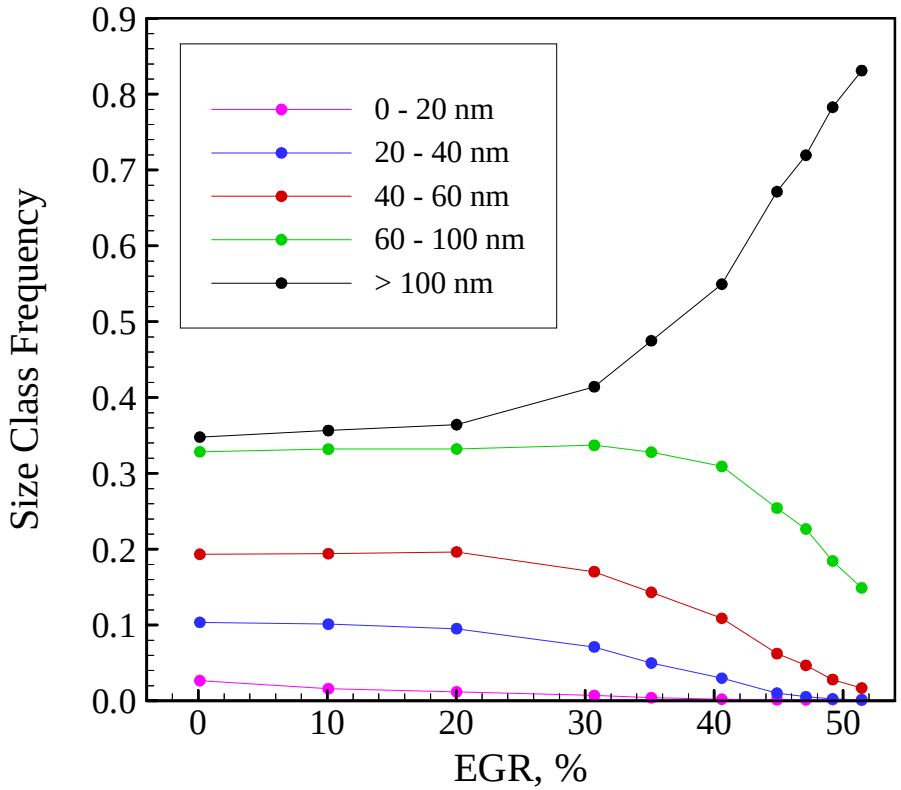
With increasing EGR:

- Median and large particles (> 100 nm) increase.
- Small particles (< 100 nm) decrease.

Hypothesis:

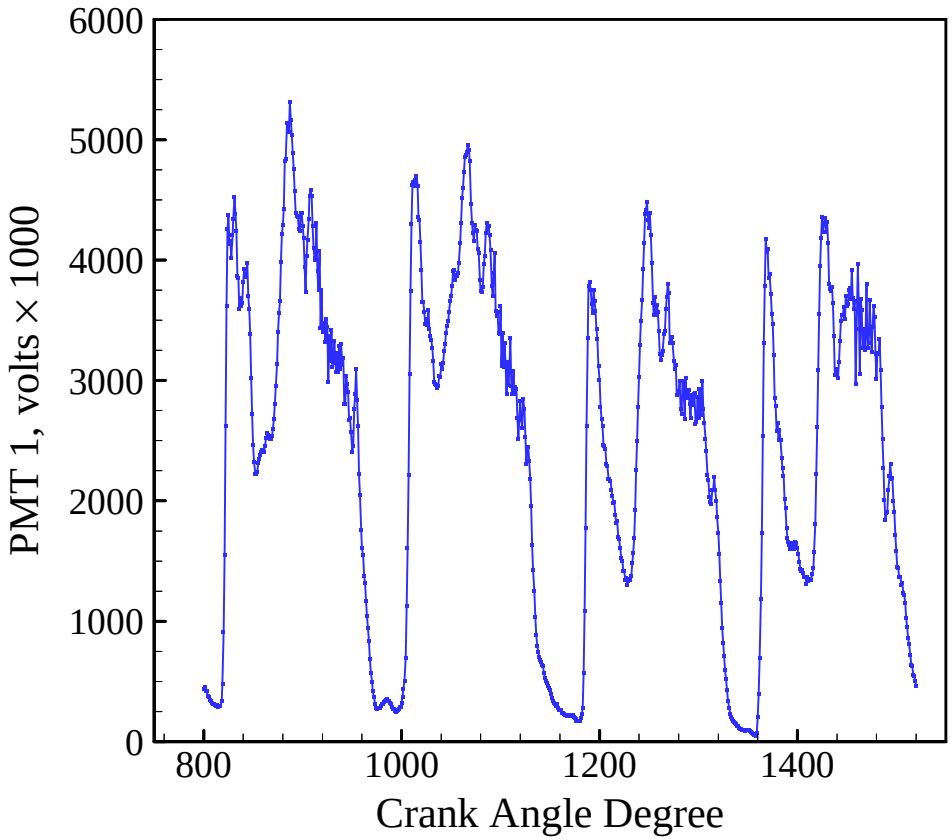
EGR particles reintroduced into combustion chamber act as nuclei for new particles and agglomerate to form larger particles.

Particle size increases with EGR



Significant increase in particle size near “break point” seen in HC, NO_x, PM

Diesel Particle Scatterometer (DPS) provides crank angle resolved PM information



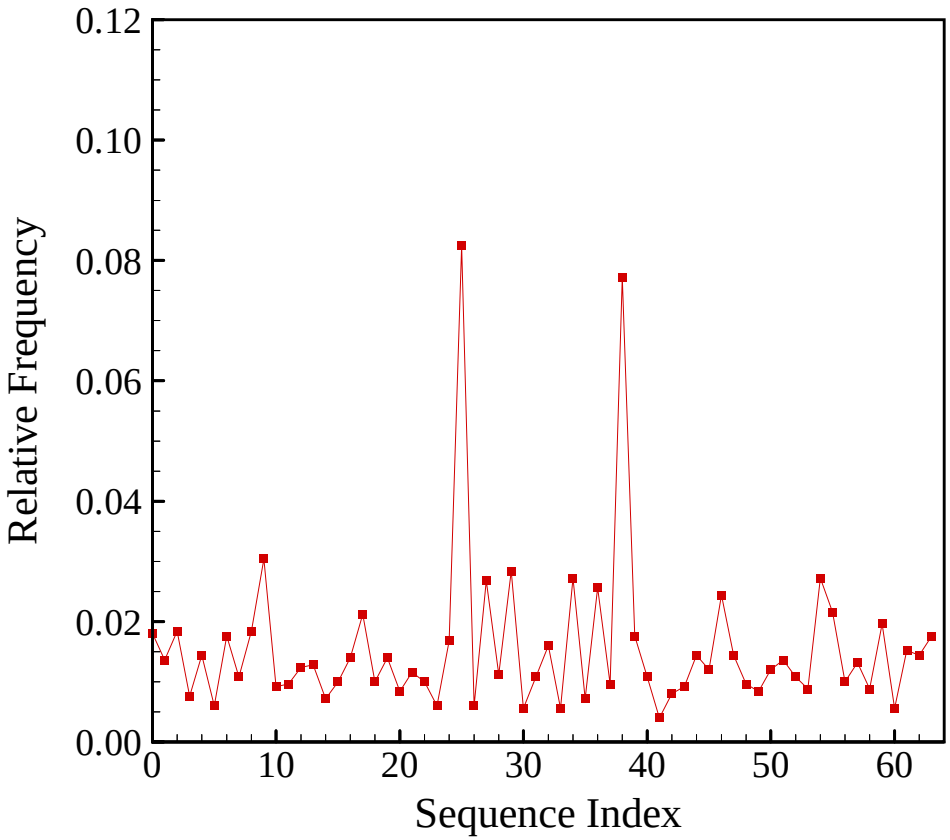
Features:

- Optical device built by LBNL and tested at ORNL.
- High-speed measurements based on optical scattering.

Observations:

- PM visible from each cylinder's combustion event.
- Will be able to provide crank angle resolved particle size distributions.

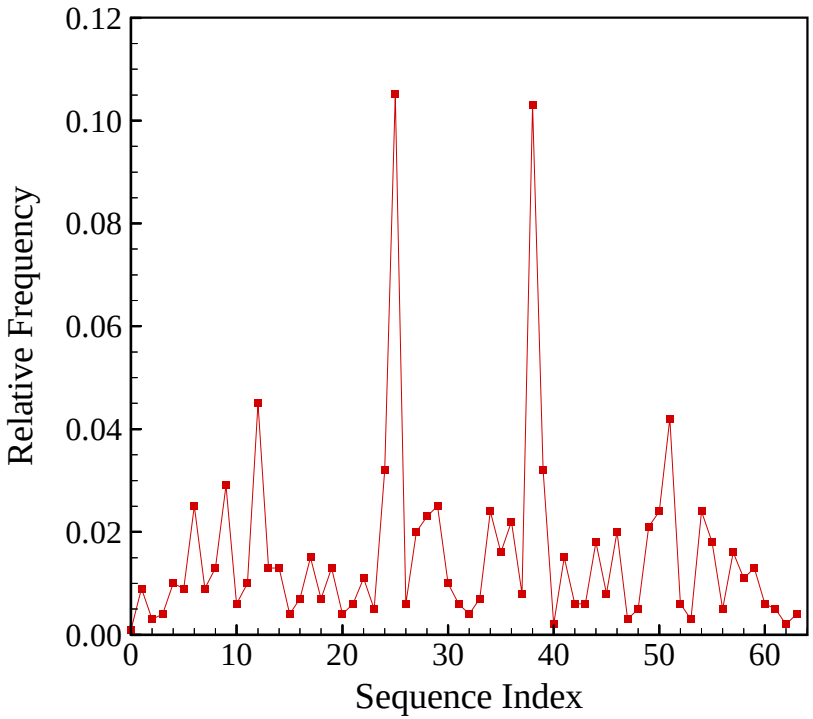
Cylinder-to-cylinder instability develops under high EGR conditions



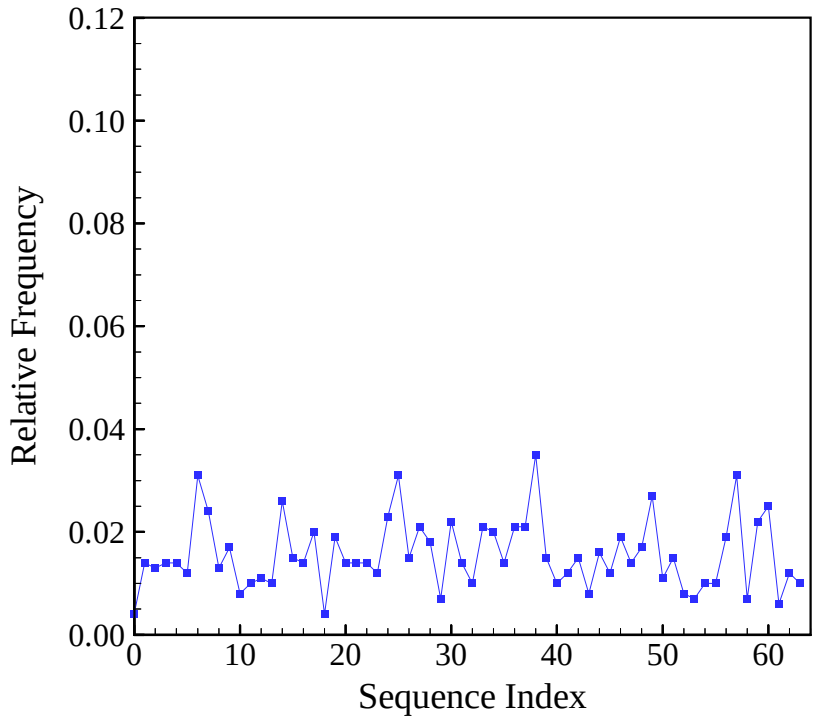
- Cylinder-to-cylinder instability represented by peaks in histogram.
- Cylinders F-0 and F-1 have significant coupling under high EGR conditions.
- Presence of coupling reveals propagation of instability.

Similar instability has been controlled in an SI engine under lean conditions by Ford/ORNL

uncontrolled

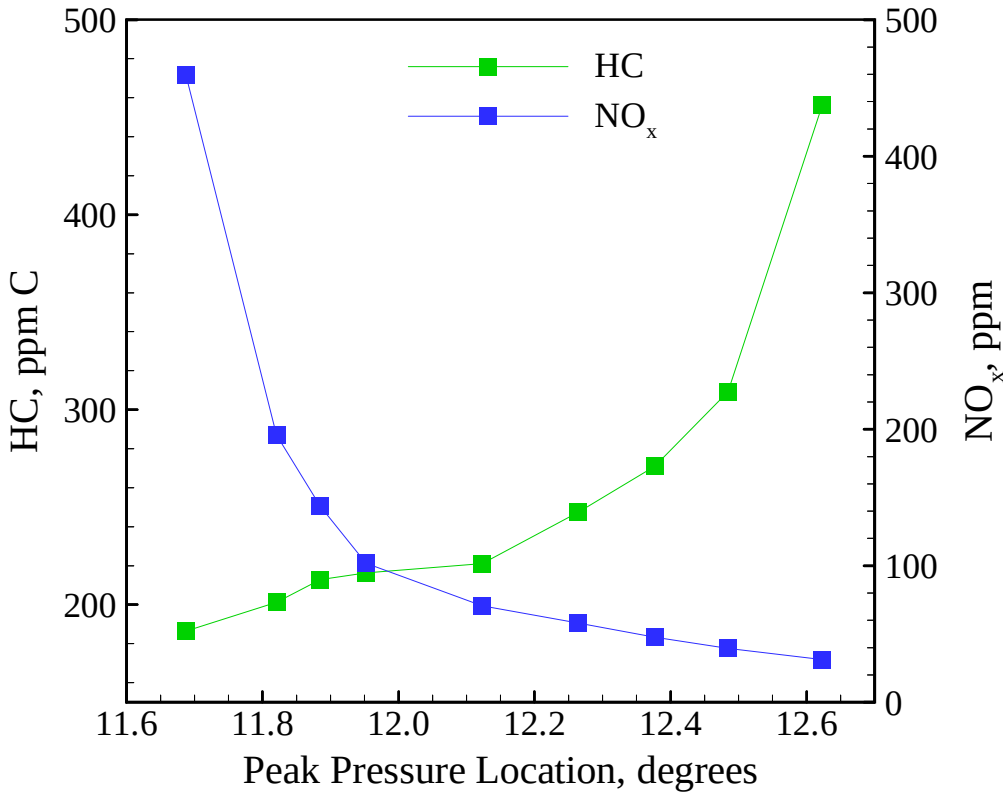


controlled



A similar algorithm will be implemented on a diesel engine under high EGR conditions in an effort to control instabilities.

Strong correlation also observed between emissions and combustion indicators



Virtual Sensor: (engine settings, crankshaft acc) → (HC, NO_x, PM)

Summary and Conclusions

- HC/PM/NO_x trade-off similar to that seen in other studies.
- Increase in EGR causes increase in PM mass emissions.
- May be possible to decrease instabilities at high EGR conditions using proven nonlinear control schemes and a virtual sensor.
- Gaseous and particle emissions correlate well with various aspects of the combustion process.

Future Plans

- Additional experiments with “fast” emissions measurements
  - Obtain real-time particle size distributions with DPS.
  - Implement Cambustion Fast NO analyzer.
- Develop virtual HC/PM/NO_x sensor concept:
  - Correlate in-cylinder pressure measurements with emissions.
  - Evaluate correlations between existing engine sensors and pressure/emissions signals.
- Develop dynamic EGR modeling/control concept:
  - Confirm ability to observe/interpret cyclic variability in emissions.
  - Map cyclic variability in emissions versus EGR parameters.
  - Contrast low-order EGR flow dynamics model.

Acknowledgements

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