On-Board Engine Exhaust Particulate Matter Sensor for HCCI and Conventional Diesel Engines

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In cooperation with

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THE UNIVERSITY OF TEXAS AT AUSTIN

Purpose of the Work

- Complete the development of an inexpensive, sensitive, accurate, and durable on-board particulate matter (PM) sensor, bringing it to a point where it can be commercialized and marketed.

Responses to Previous Year Reviewers' Comments

Specific Weaknesses:

– Probably need to look at effects of PM composition on sensor signal (i.e. oil additive contributions and variations).

Project Changes: Current plan is to use Cummins 2007 engine which will likely have a very different exhaust PM composition from current single-cylinder engine.

Recommendations/Additions to or Deletions from the work scope

• Interesting and potentially valuable technique. Continue development of sensor and understanding of underlying physics.

Project Changes: A much better understanding of underlying physics has been achieved since review.

Barriers/Challenges

- Improve durability and reduce sensor vibration noise

New designs created in the last two months incorporating a heating element show marked improvement in durability, but erratic behavior is still observed under some conditions.

- Account for velocity dependence of sensor output

Pulsating exhaust flow from single-cylinder engine proved too difficult to use to quantify velocity dependence.

Steady-state flow rig to study velocity dependence under construction.

- Improve reliability of detection electronics

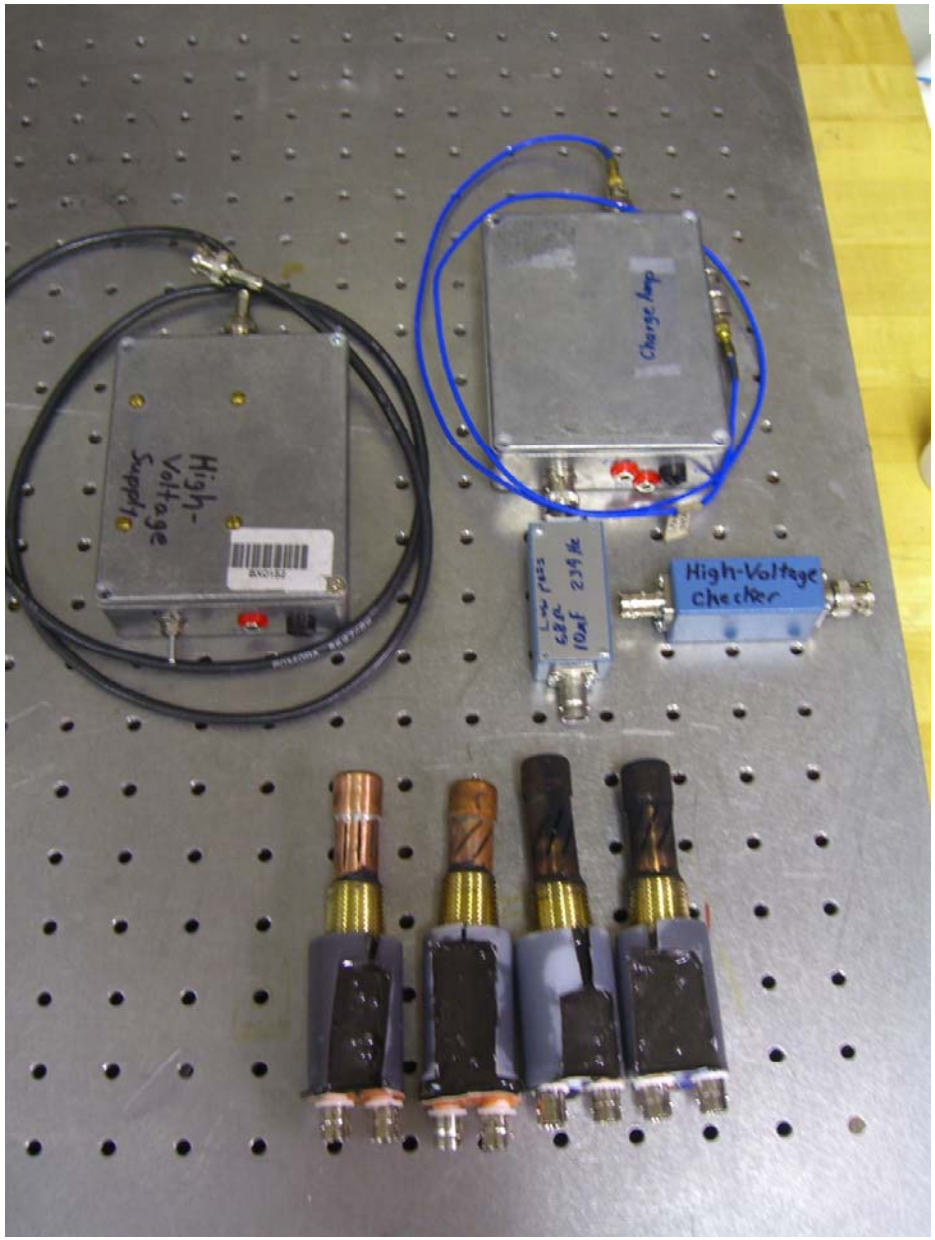
I.C. chips in signal detection circuit will occasionally fail.

Need to test different op amps and circuit designs.

Approach: Sensor Operation

- Carbonaceous PM in the exhaust gases form an electrically conductive channel between two electrodes in the sensor
- Sensor: Approximately the size of an automotive spark plug or oxygen sensor
  - High voltage D.C. bias given to one electrode (typically 1000 V)
  - Second electrode connected to custom built detection electronics

Sensor electronics and 4 sensors of old design

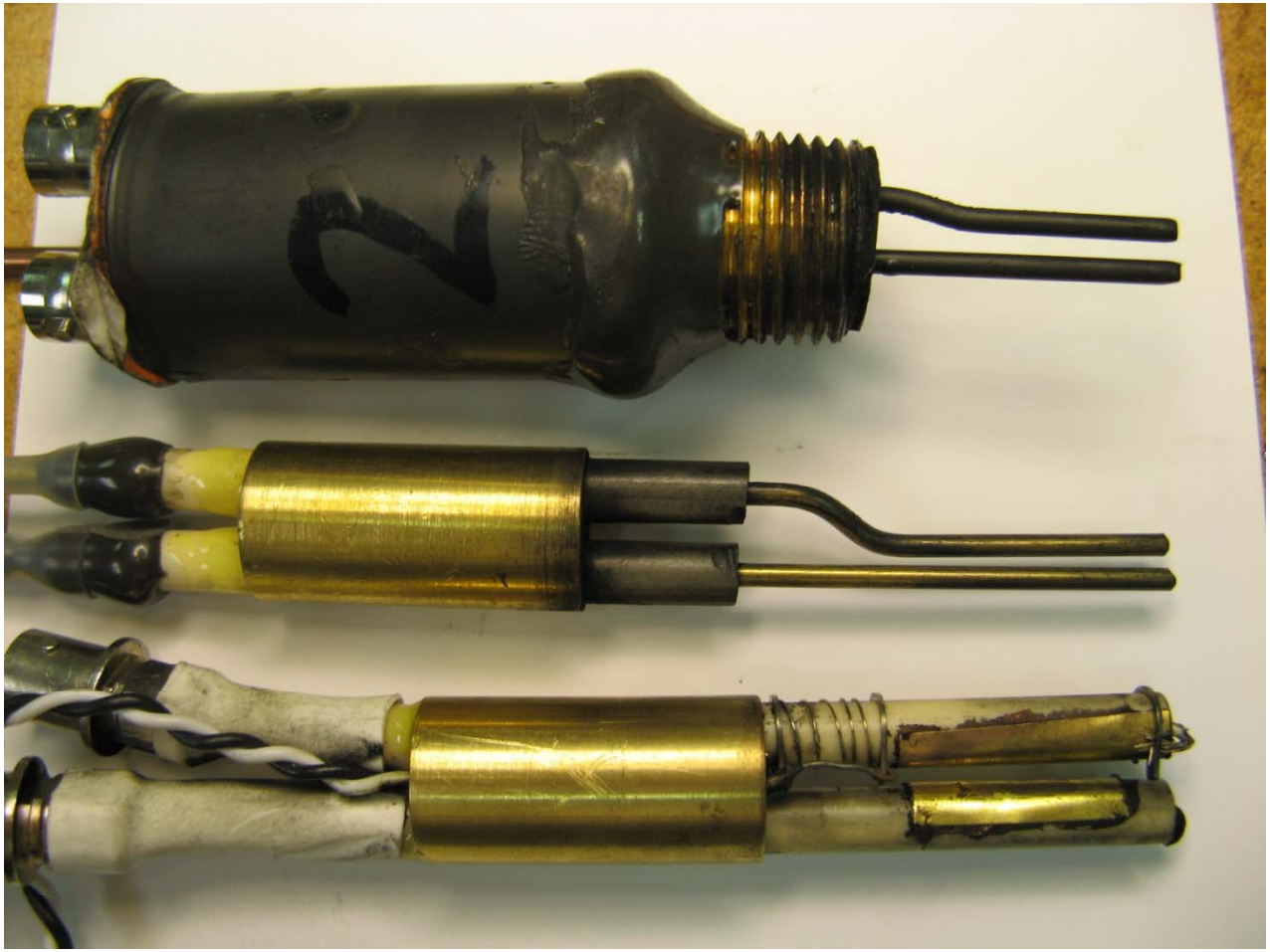


Approach: Major Tasks for FY-08
Phase 2 (Budget Period 2)

- Identify qualified sensor commercialization partner.
- Complete set up of the 6.7 L Cummins light-duty engine on a dynamometer test stand.
- Measure and document sensitivity, time response, and durability of the best PM sensor in the exhaust of the 6.7 L Cummins engine.
- Measure and document sensitivity, time response, and durability of the best PM sensor in the exhaust of the heavy-duty Cummins engine operating as diesel and make preliminary measurements in HCCI mode (to be performed at Cummins).
- Optimize sensor design for high durability and sensitivity.

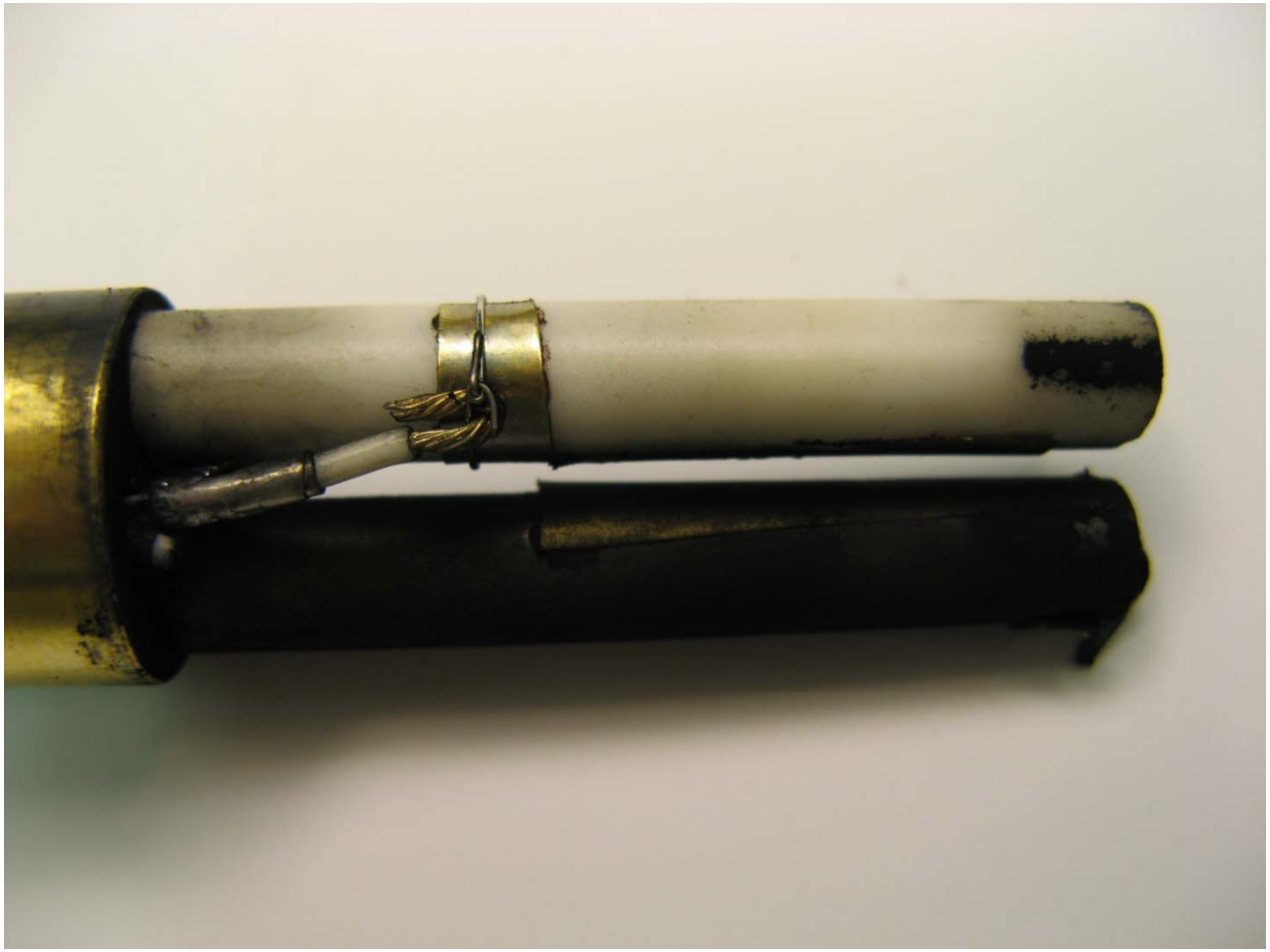
Accomplishments/Progress/Results

Evolution of Sensor Designs
air purged, shrouded electrode, foil electrode

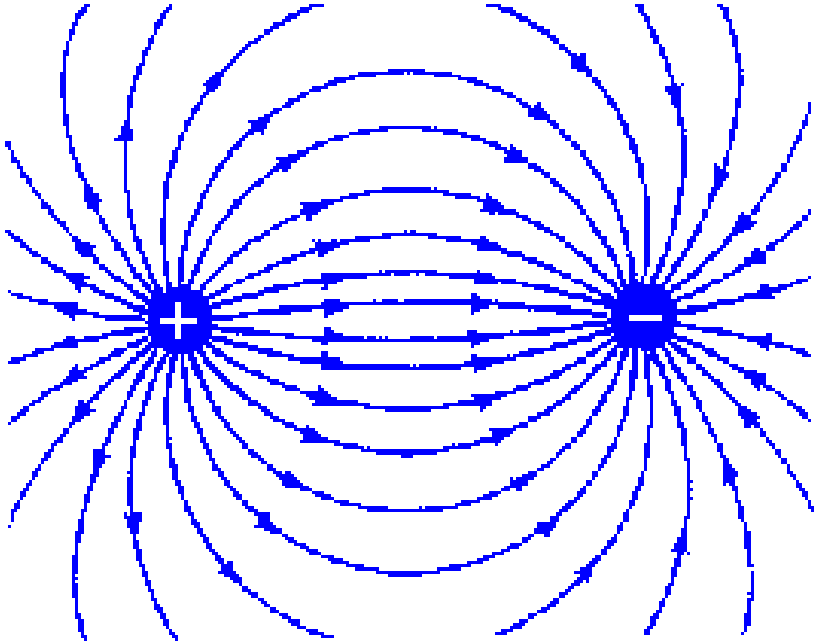


Accomplishments/Progress/Results

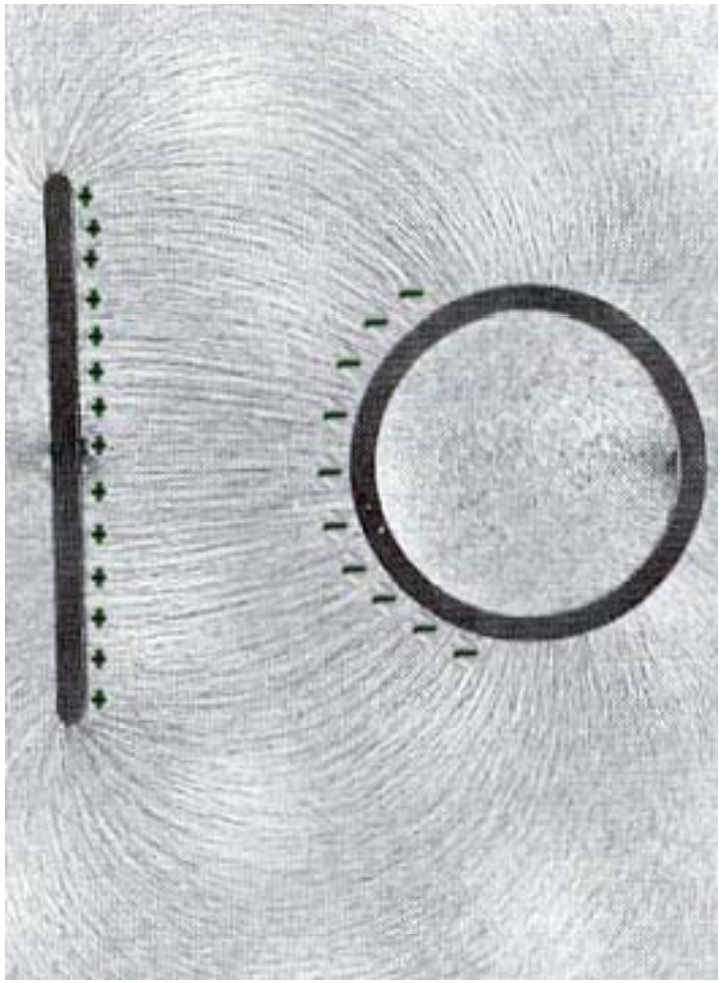
Newest sensor having internal heater on sensor electrode side



Electric field lines for two point charges and for plate and circle

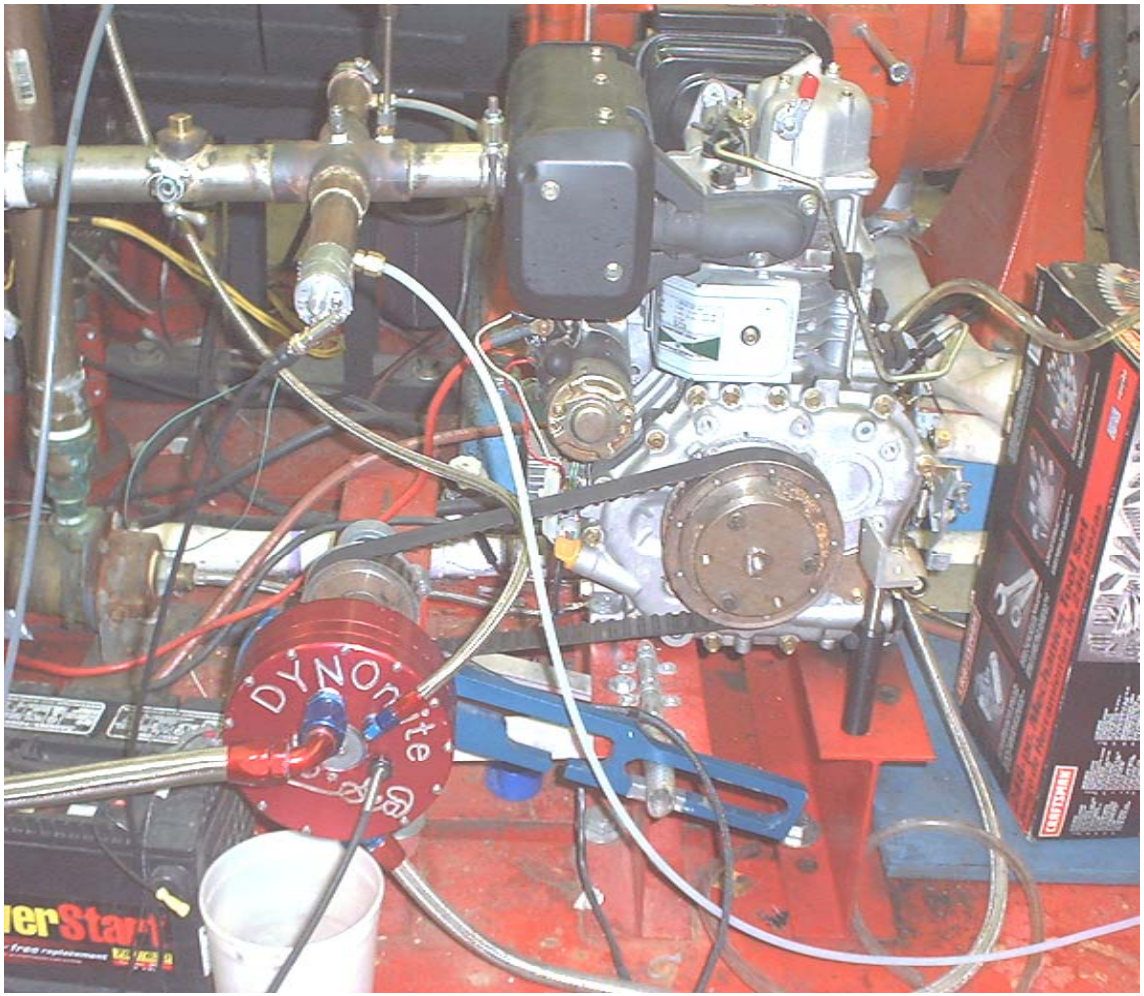


Opposite point charges

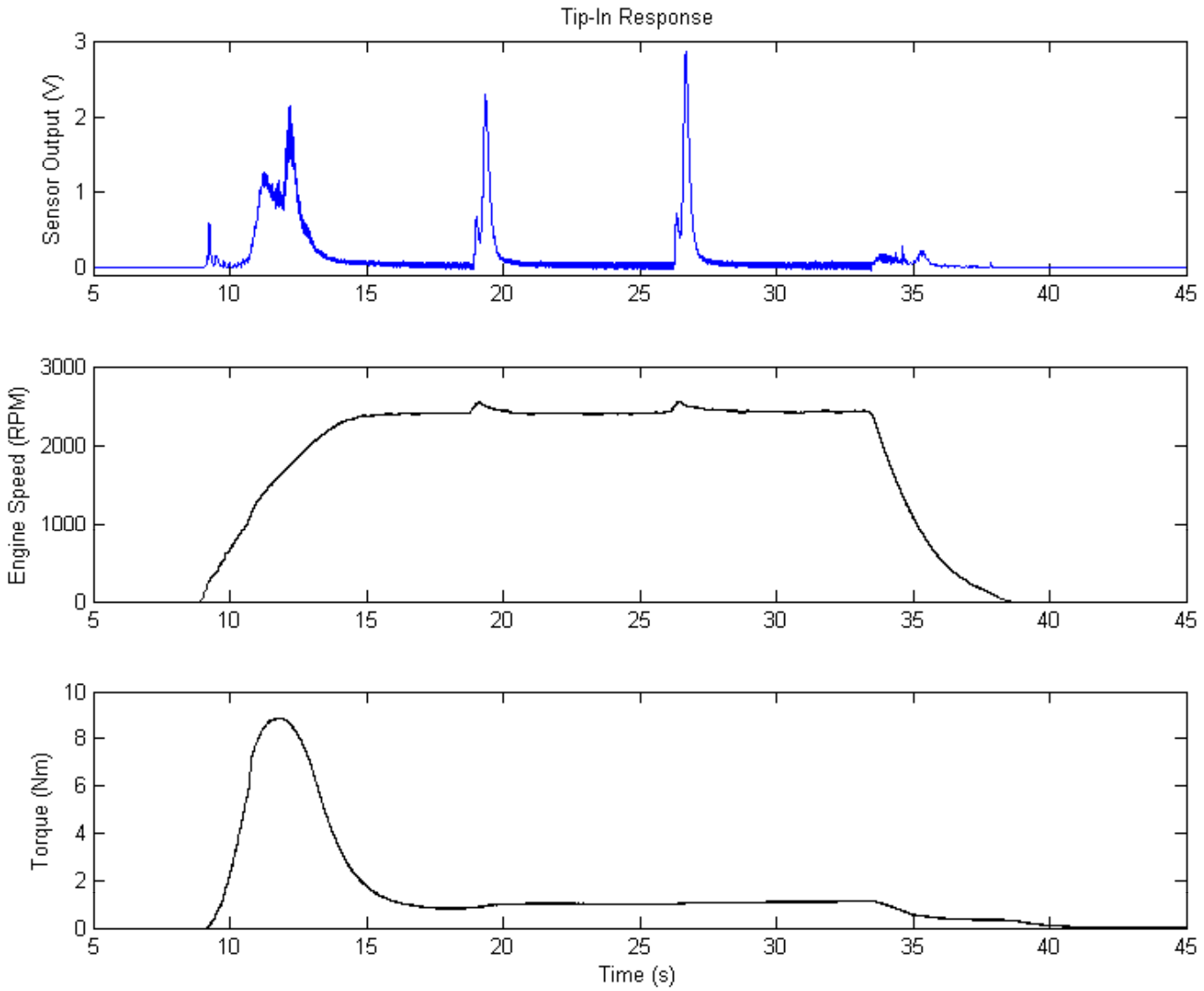


Charged plate and circle

Single-Cylinder Diesel Engine Test Setup

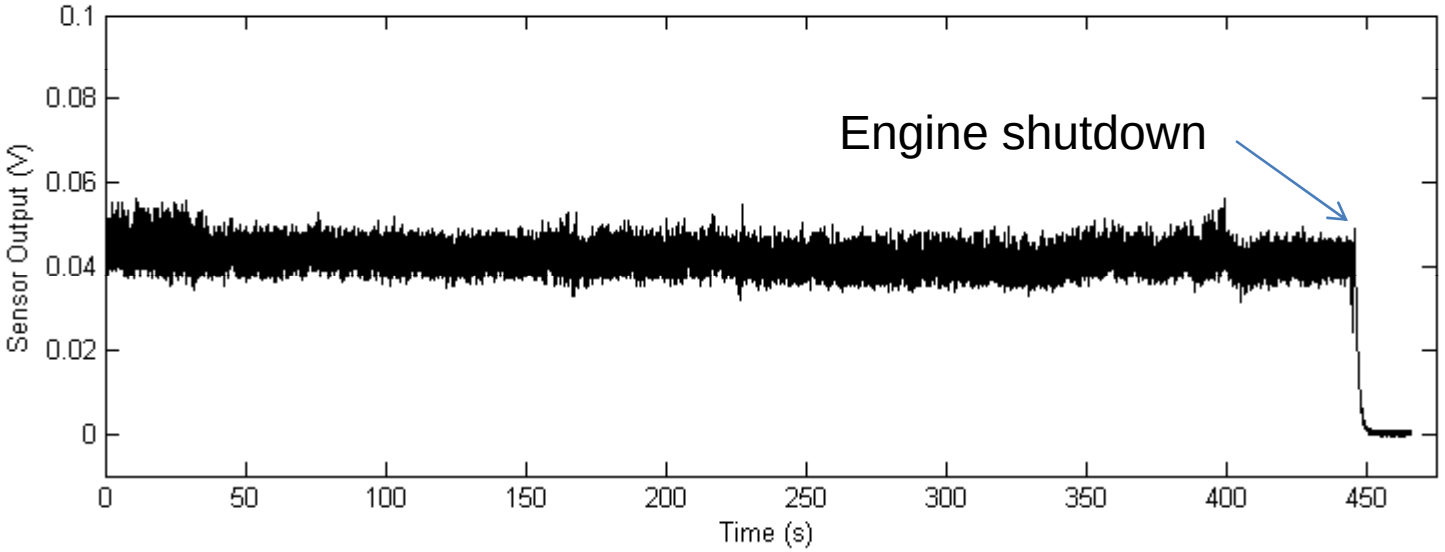


Sensor behavior for start-up, two tip-in events and shutdown

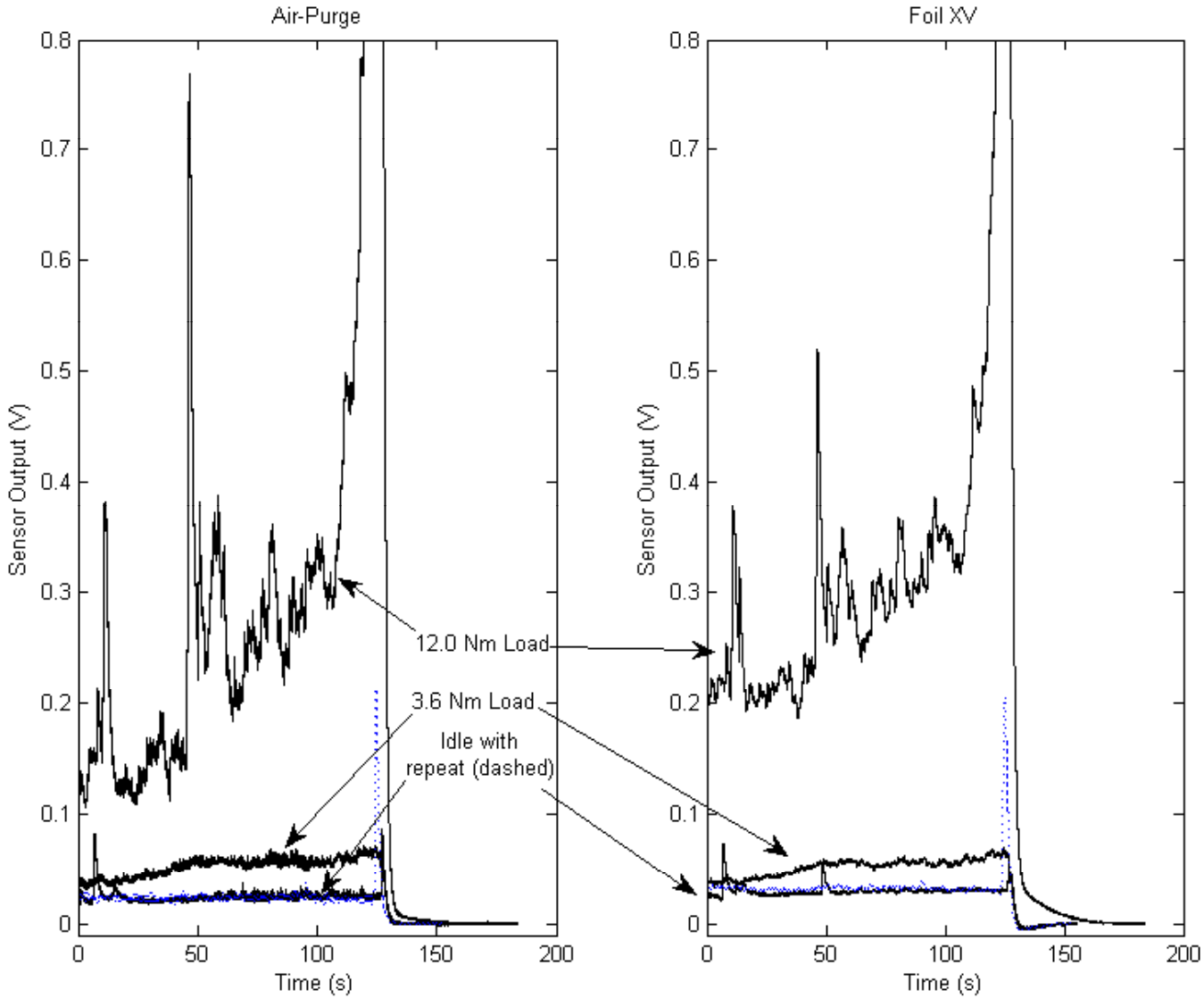


Exploration of sensor resolution and sensitivity limits

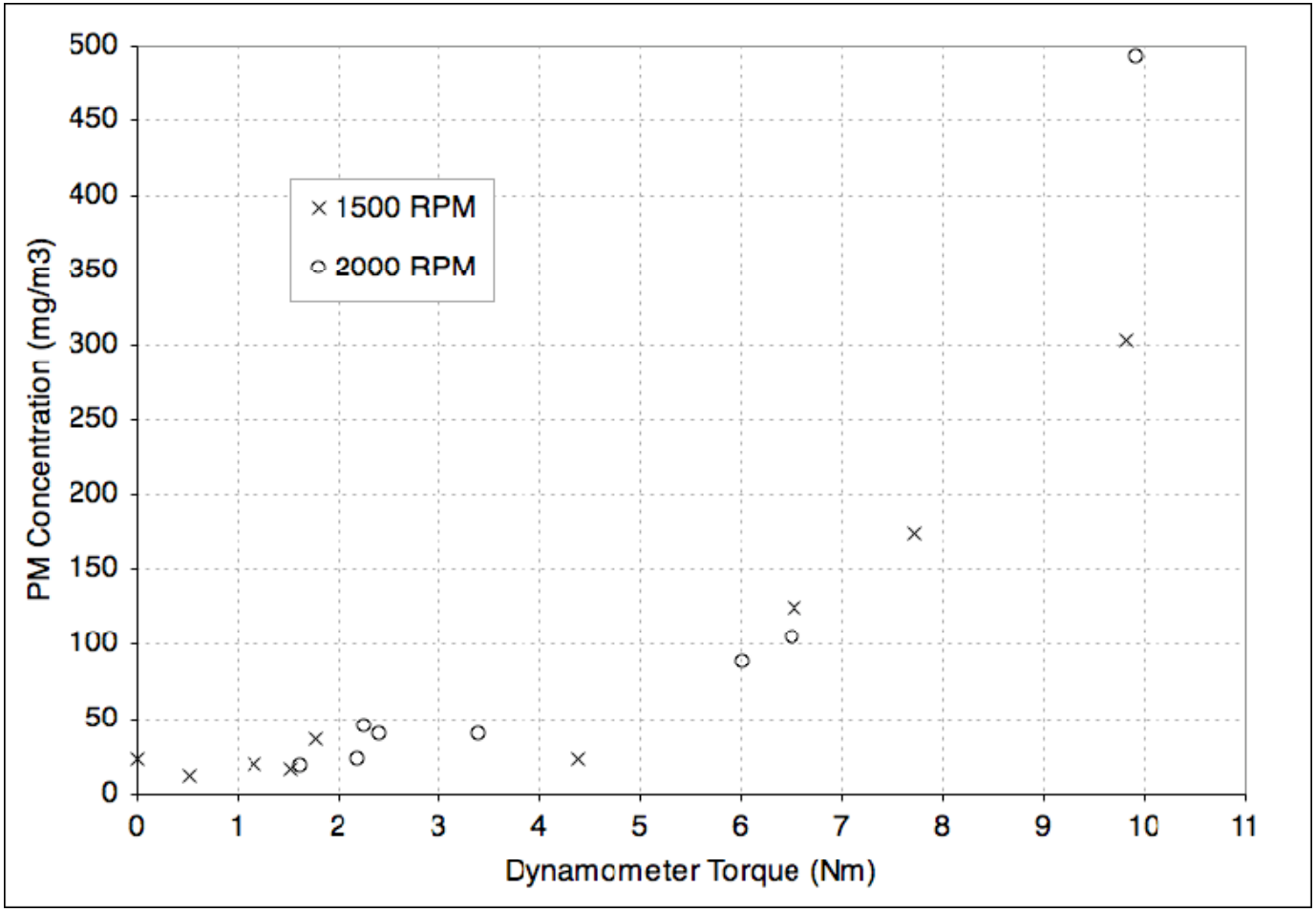
1500 rpm at a very low load of 1.5 Nm torque
Simultaneous filter measurement gave 17 mg/m^3 dry PM mass



Simultaneous measurements with air-purged (left) and new foil-electrode sensor (right)



PM mass concentration measured with filters versus engine torque output



Technology Transfer

- Actively working with industrial partners:

  Cummins Engine Co. (sensor testing and development)

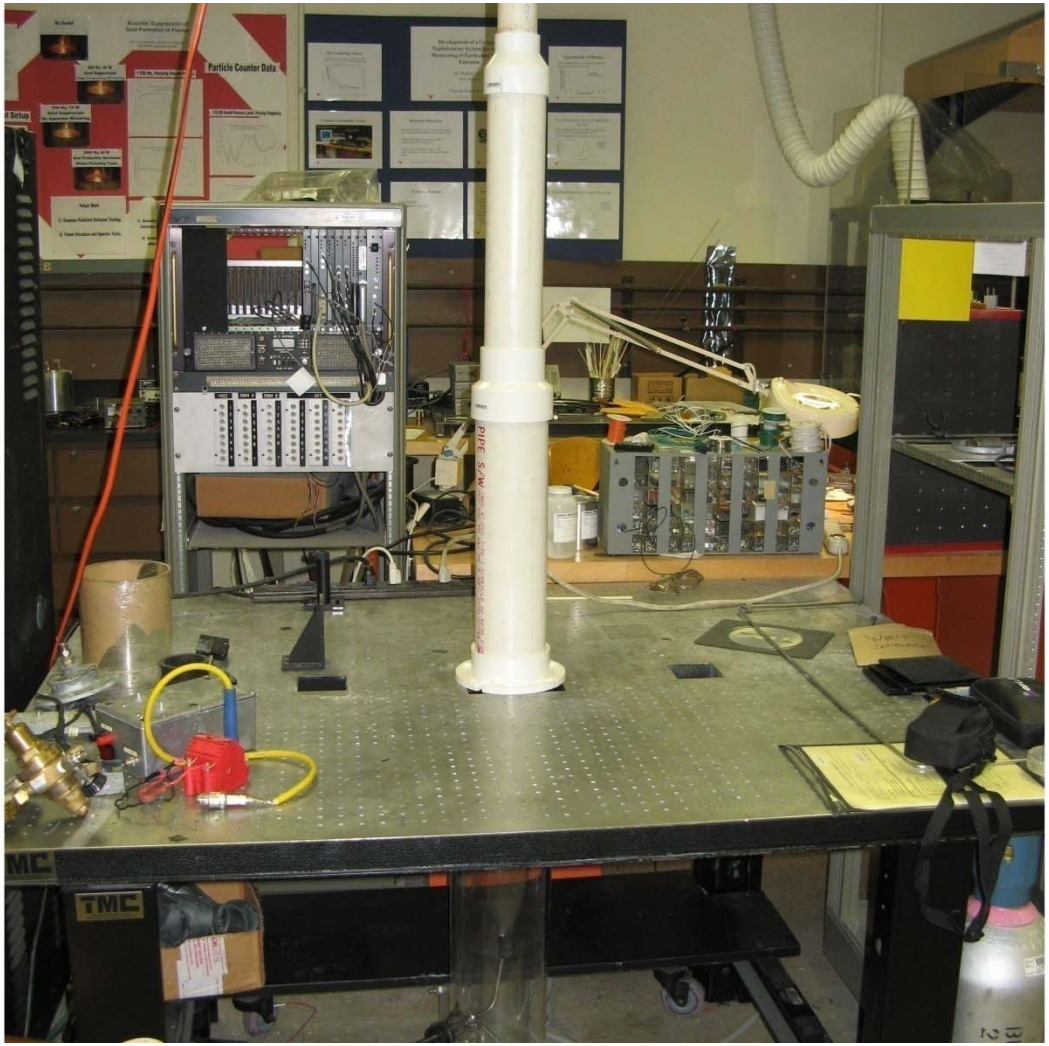
  Ceramatec Inc. (sensor manufacturing and commercialization)

  Licensing agreement signed February 2008

Activities for FY-08

- Work on new sensor designs having integrated heater and improve sensor system electronics
- Complete steady-state PM rig and investigate velocity dependence of sensor
- Set up new 2007 Cummins engine on dynamometer at UT
- Test new sensors in Cummins engine exhaust for durability, sensitivity, PM resolution, and time resolution
- Supply sensor system to Cummins for heavy duty engine testing and preliminary HCCI measurements
- Investigate effects of sensor fouling on sensor sensitivity
- Work with commercialization partner on sensor design and industrial testing.

Construction of steady-state flow rig with acetylene burner to be used for investigation of sensor velocity dependence



Summary

- The UT PM sensor shows promise as an enabling technology for improvements to diesel engine emissions control and perhaps for diesel HCCI individual$_{cy}$ linder control.
- Our goal is to further improve sensor durability and sensitivity through experimental investigation and to assess velocity dependence.
- The sensor durability has been improved through active heating to reduce fouling. Sensor failure mechanisms and have been identified and underlying physics are better understood. Sensitivity has been assessed and has been improved by the development of the foil-electrode-type sensor
- A licensing agreement between UT and Ceramatec, Inc. was signed in February 2008 to jointly pursue commercialization.
- FY-08 plans include: refinement and characterization of new sensor designs, completion of steady-state rig to study velocity dependence, testing with 2007 Cummins light-duty diesel and Cummins heavy-duty/HCCI engine.

Publications/Patents

- Patent

2443 - A Sensor to Measure Time-Resolved Particulate (soot) Exhaust Emissions from Internal Combustion Engines has been patented with coverage in the US in the form of a PCT that was nationalized in the US.

- Provisional: 7/19/2002
- PCT conversion: 7/18/2003
- Nationalization in the US: 1/19/2005

- Publications

- Diller, T.T., Hall, M.J., and Matthew, R.D. “Further Development of an Electronic Particulate Matter Sensor and Its Application to Diesel Engine Transients,” Society of Automotive Engineers Paper 2008-01-1065, 2008.

- Hall, M.J., Diller, T.T., and Matthew, R.D. “Fast-response electronic particulate matter sensor for diesel engine control and DPF failure detection,” submitted for the 2008 AVL International Conference on Engine Combustion Diagnostics, Baden-Baden, Germany, June 10, 2008.