

Smart Materials for Fuel Injection Actuation

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Detroit Diesel Corporation

The demands of stringent emissions and a robust engine dynamic torque response characteristic require innovative, accurate and repeatable control of the fuel injection event.

Recent advances in piezo-material actuators have warranted the pursuit of its application to advanced heavy-duty truck fuel injection systems. This presentation will report on design and testing of an advanced electronic unit injector for the Detroit Diesel Series 60 truck engine.



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Outline

- **Prototype Development**
 - **Stack design with ACX**
- **Fixture Tests**
- **Engine Tests**
- **Conclusions**

Electronic Unit Injectors (EUI)



Solenoid EUI



Piezo EUI

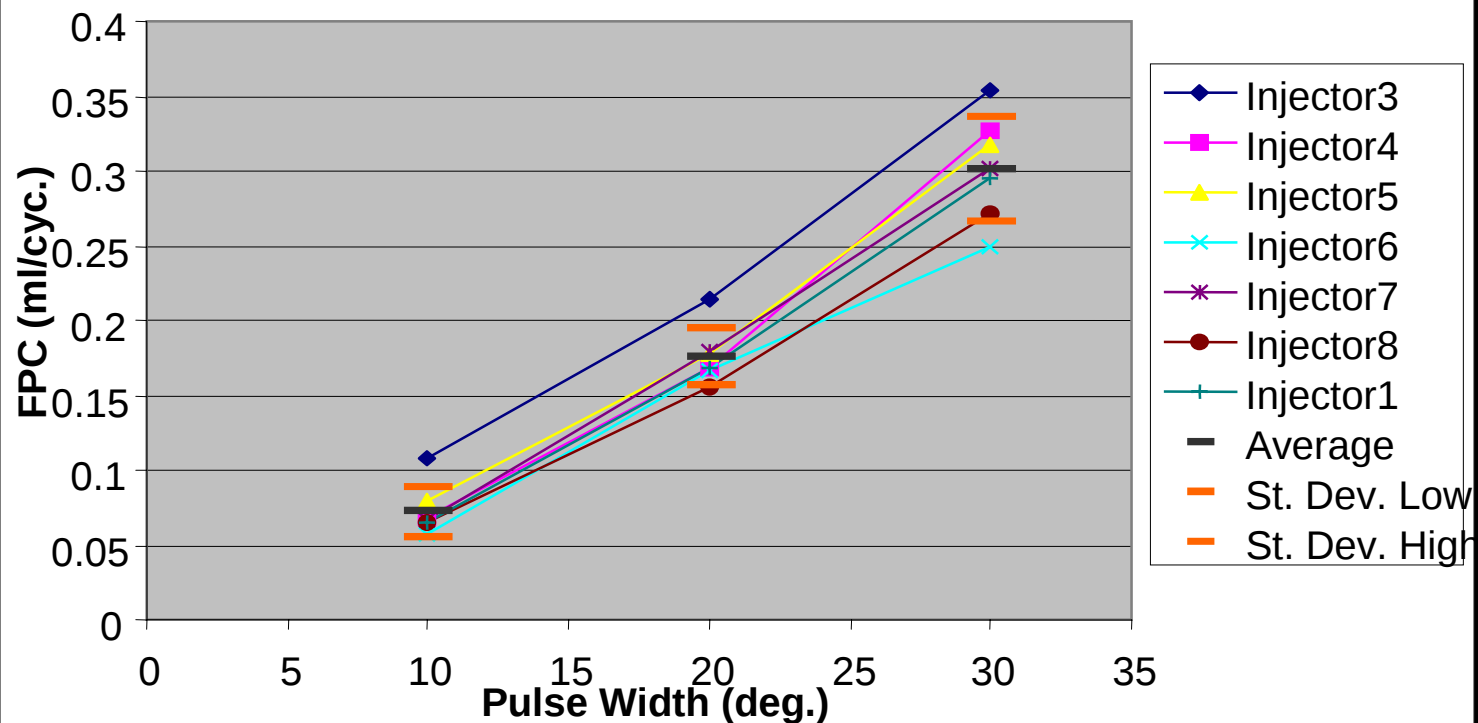
Piezo Injector Fixture Test Results

Global Head Fixture Tests

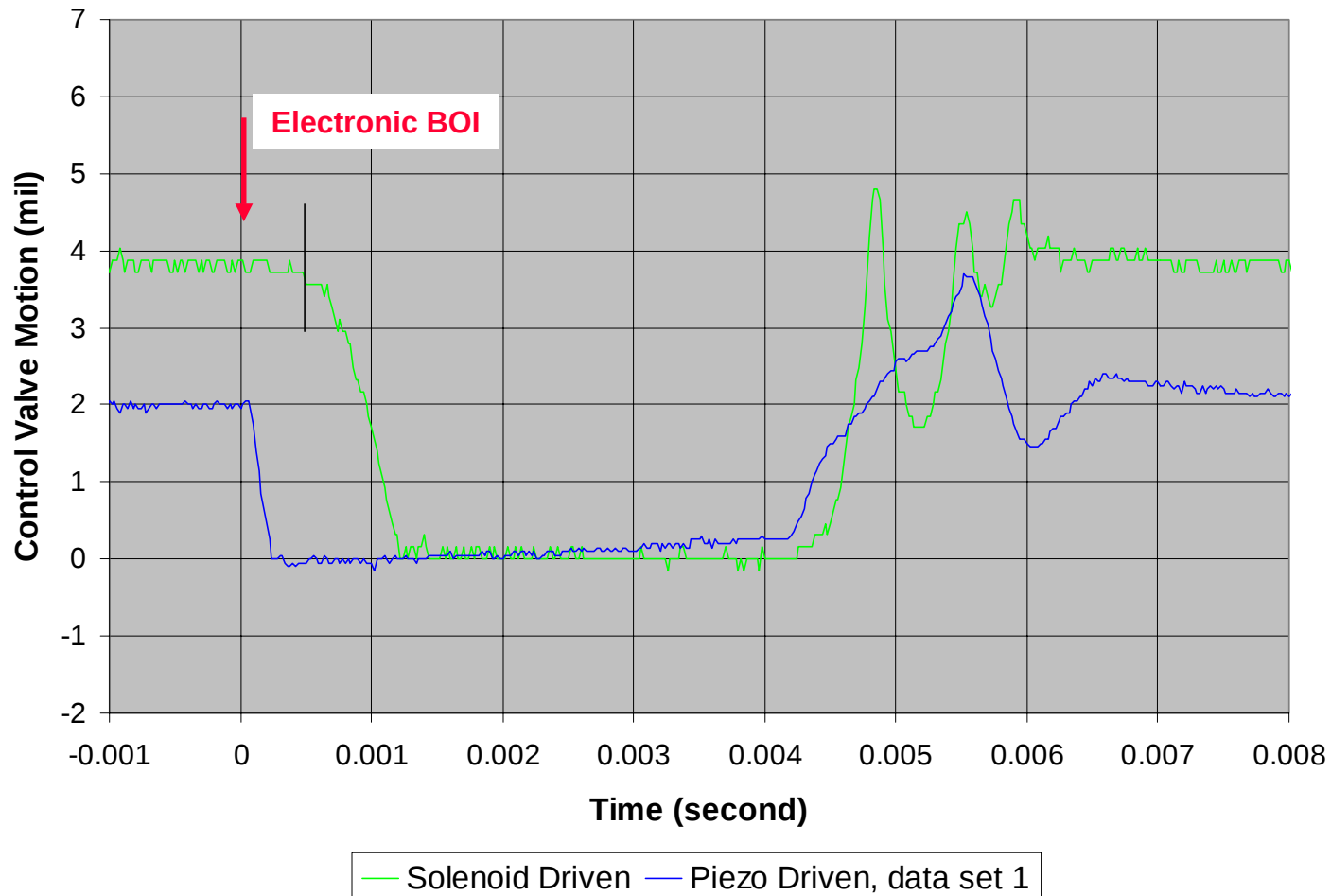
- **Characterize piezo injectors**
 - Injection quantity
 - Injection pressure
 - Dynamics of control valve
- **Evaluate performance**
 - Injection control
 - Injector mounting interference
 - Actuator capability in engine environment

Injection Quantity

Engine Speed=1200 rpm



Comparison of Control Valve Dynamics



Comparison of Control Valve Dynamics

- **Actuation delay**
 - order of magnitude shorter for a piezo
- **Control valve rise time**
 - three times faster for a piezo

Fixture Test Summary

- **The piezo actuator has a shorter actuation delay and faster rise time**
- **Piezo actuator has a different dynamic behavior, thus different control strategy is necessary**

Piezo Injector Engine Test Results

Engine Test Approach

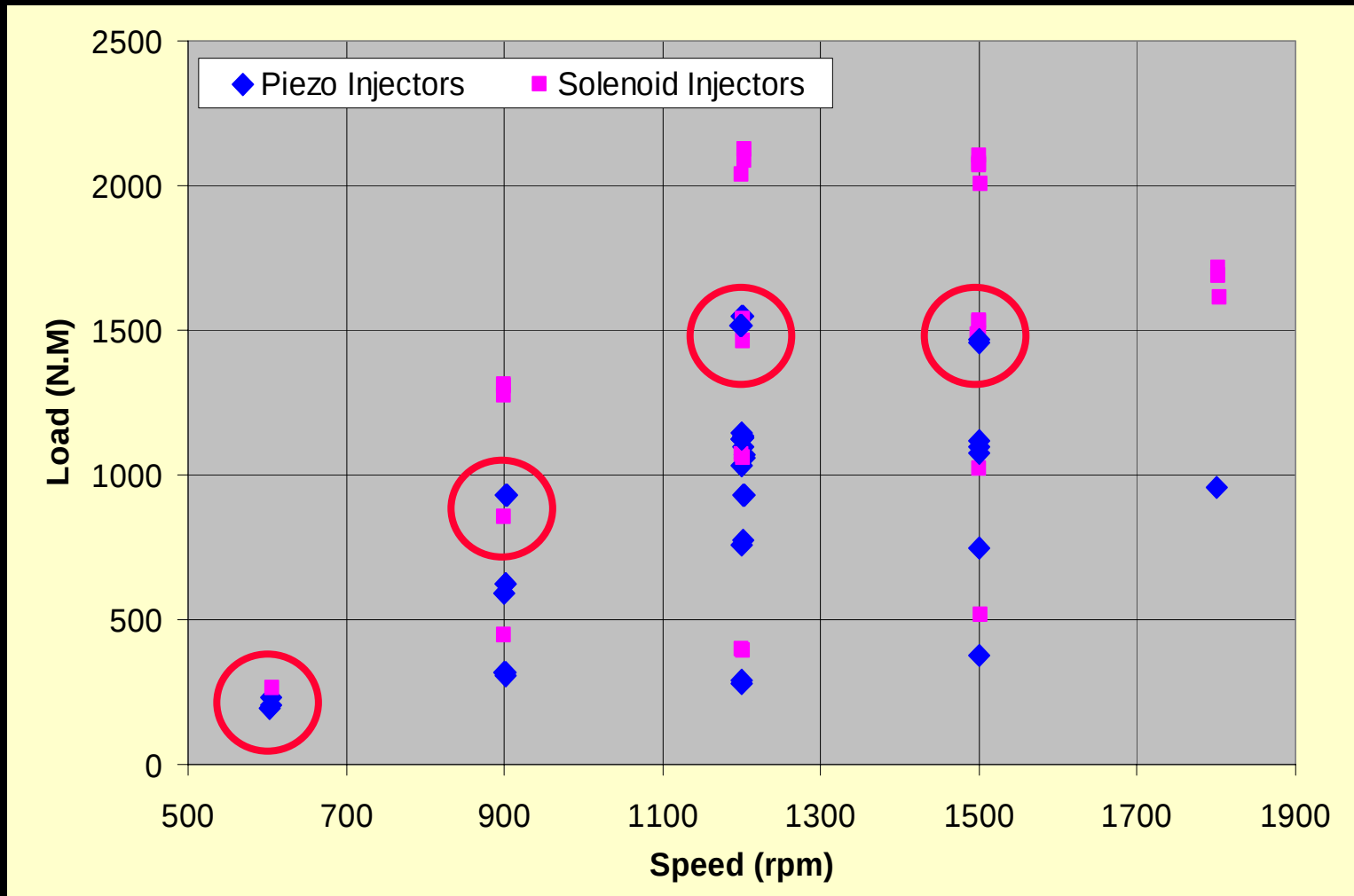
- **Baseline performance and emissions of solenoid EUI at full range of speed and load**
- **The piezo injector performance on the same engine using the same instrumentation**

Engine Test Setup

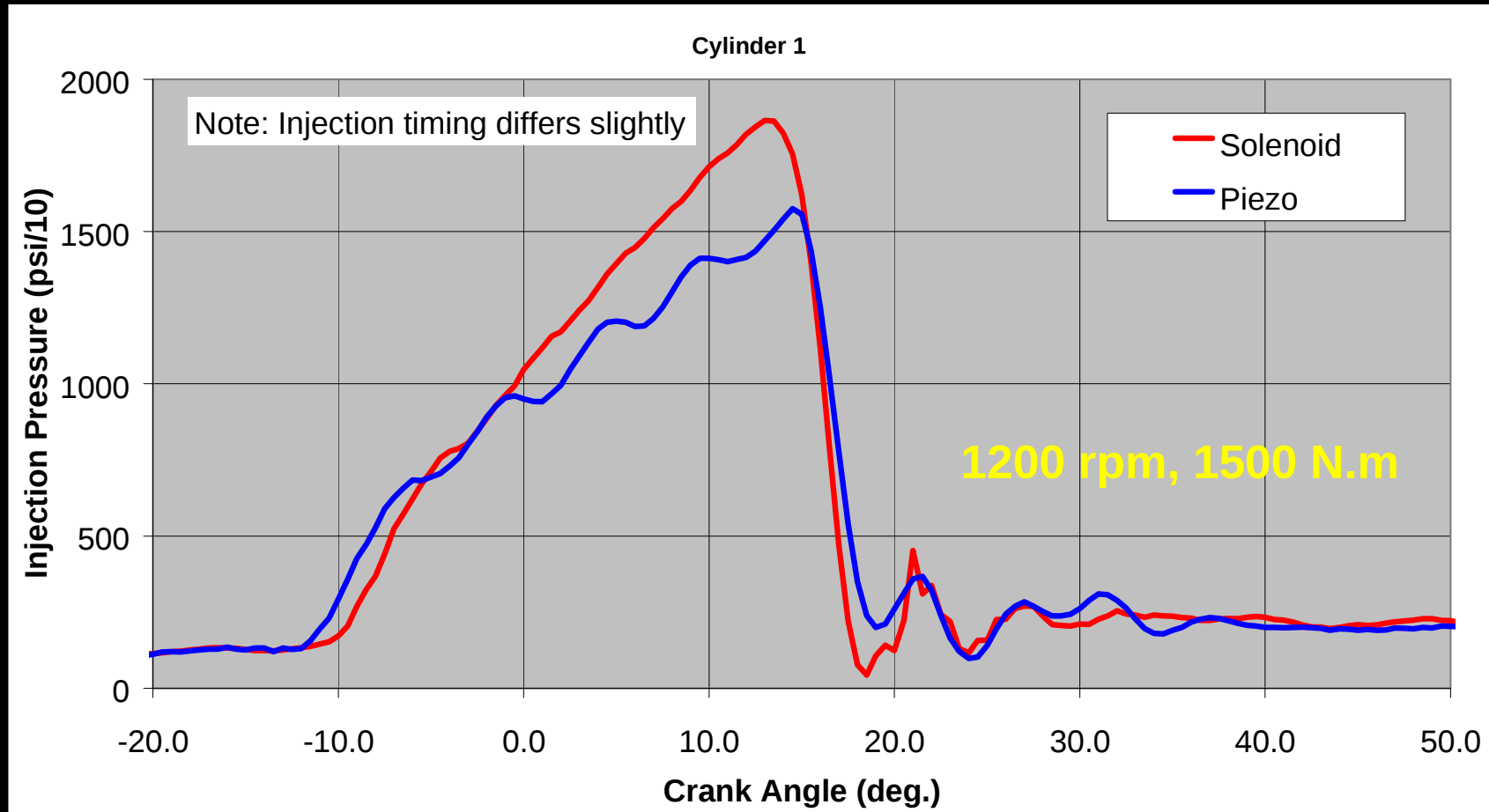


DEER Workshop, August 2000

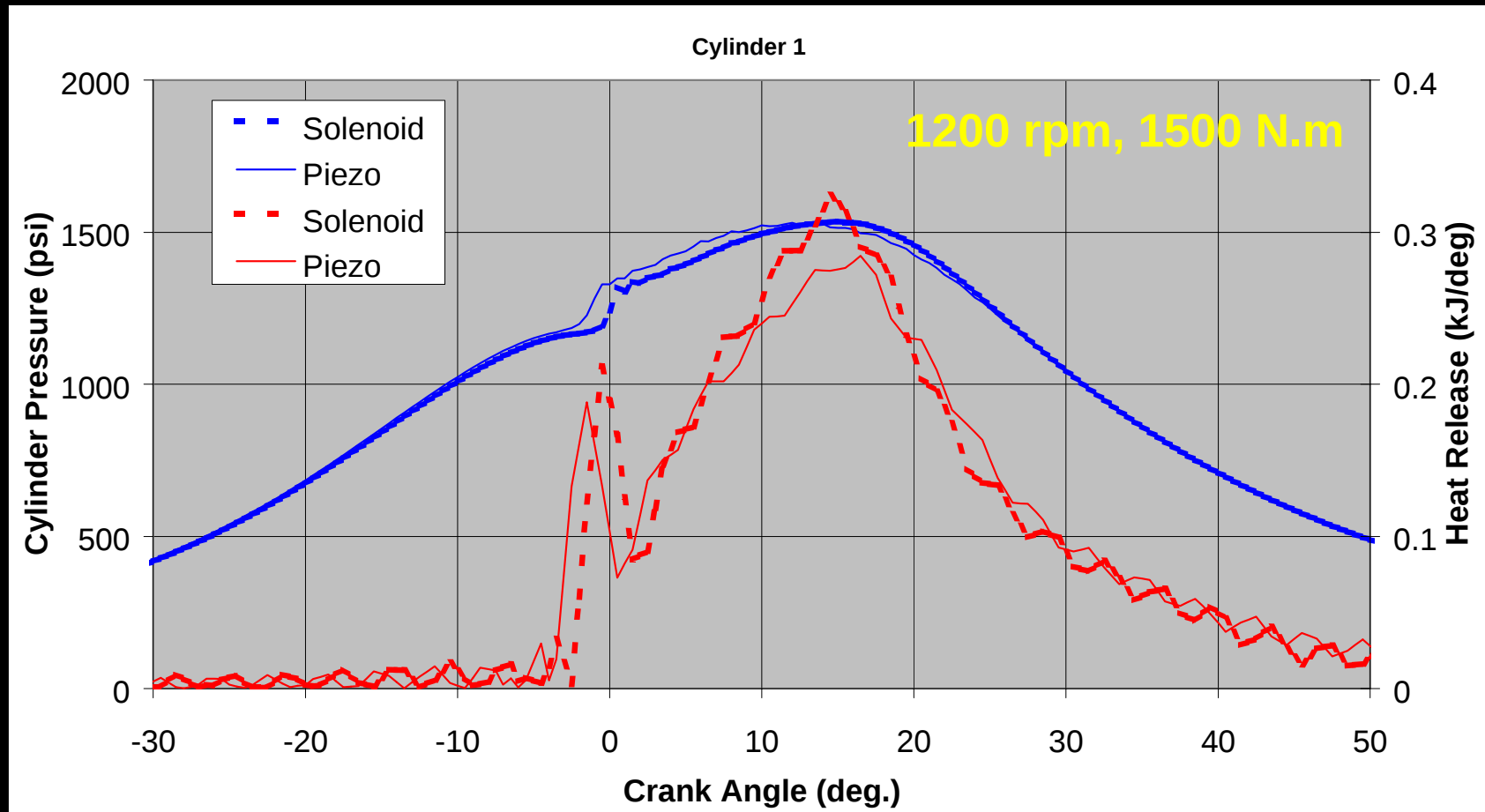
Engine Test Range



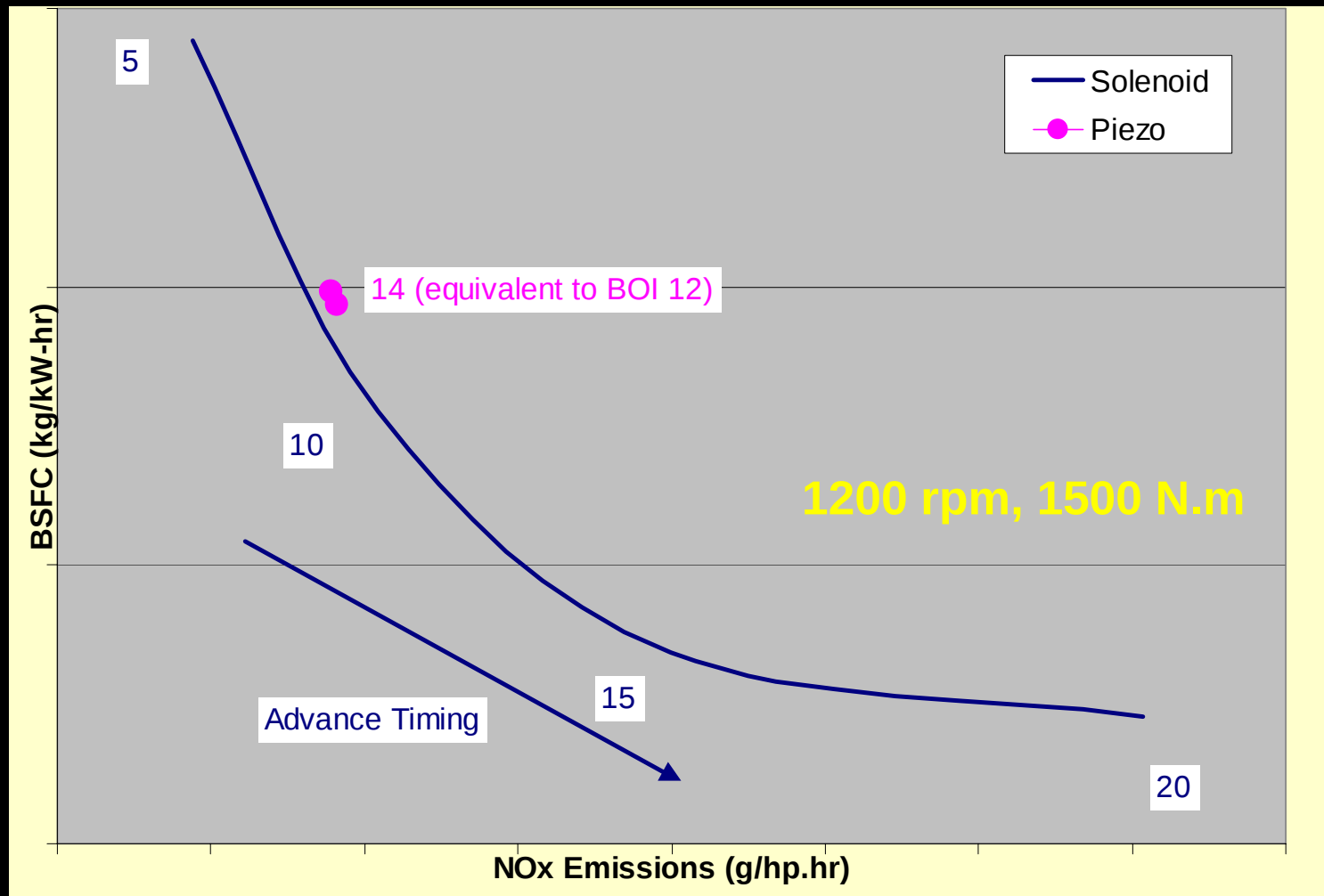
Injection Pressure



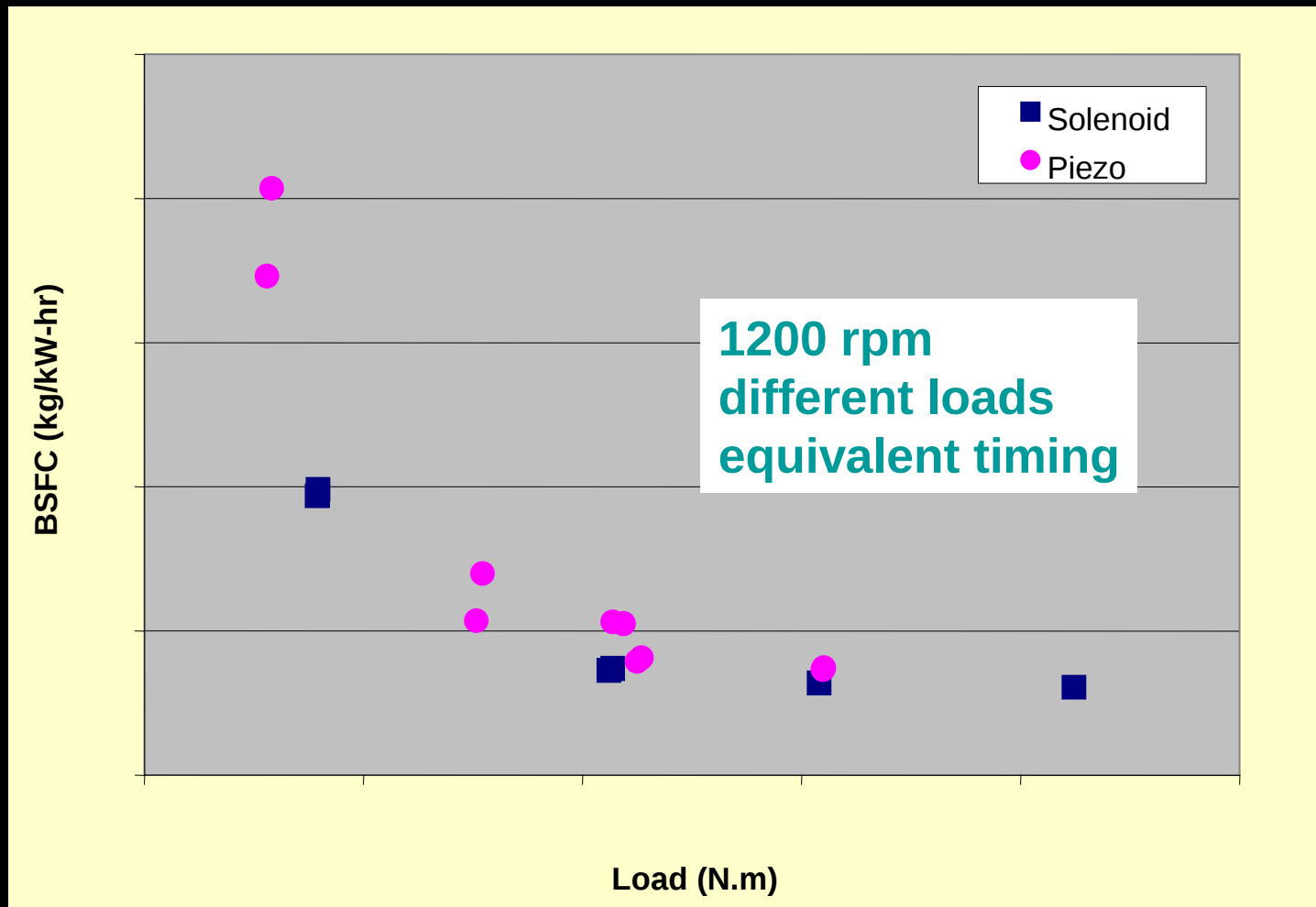
Combustion Event



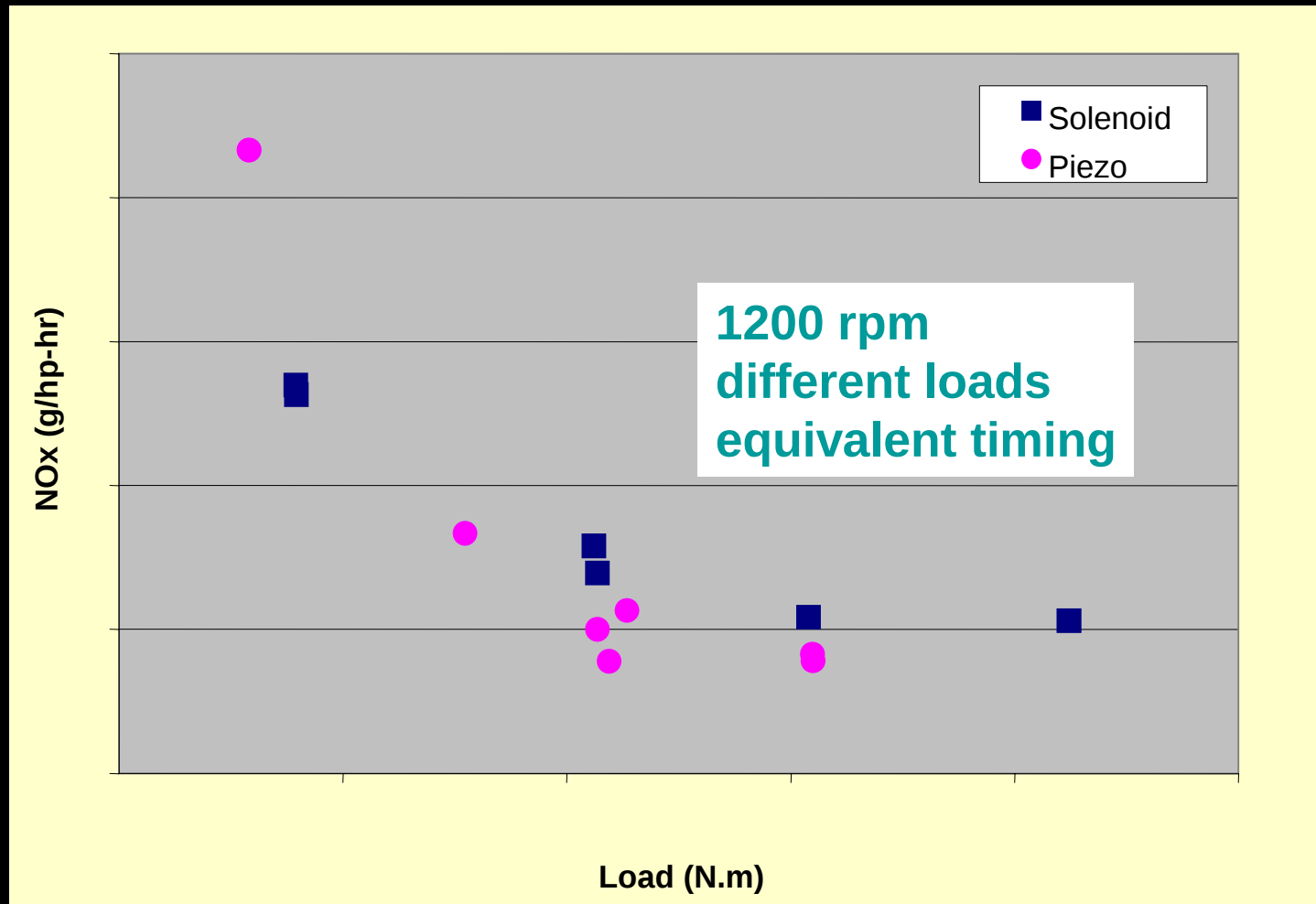
NOx and BSFC



BSFC vs. Load

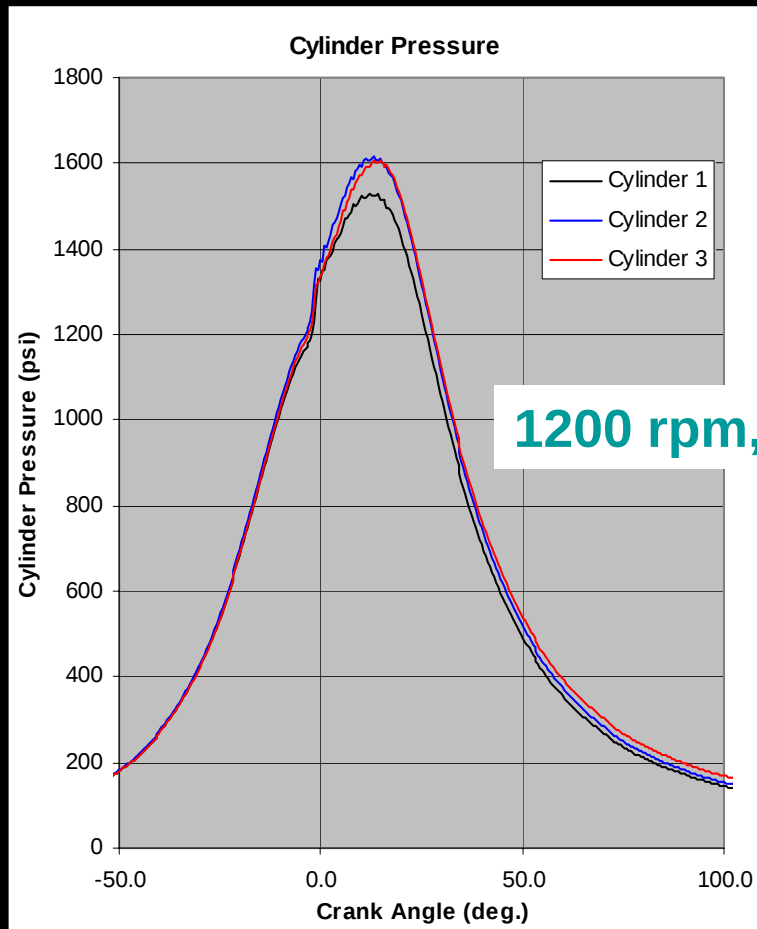


NOx vs. Load

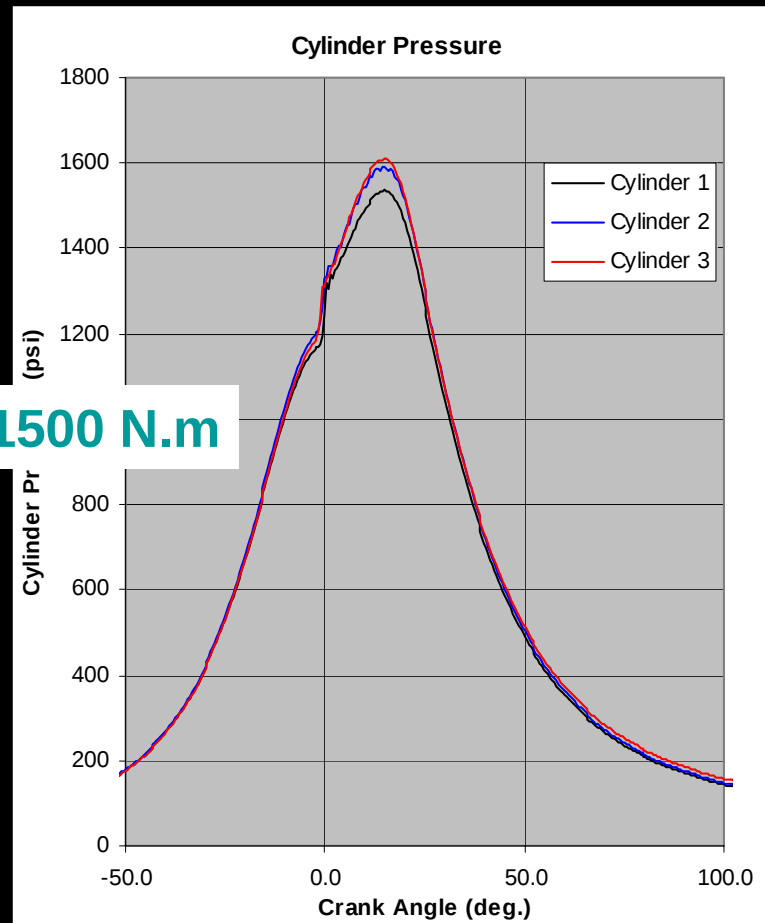


Cylinder Pressure Variation

Piezo



Solenoid



Engine Test Summary - general

- **Engine speed up to rated level**
- **Engine load up to 75% rated level**
- **Continuous operation up to 6 hours**
- **Normal firing engine environment**

Engine Test Summary - fuel economy

- **Comparable BSFC at lower speed**
 - adequate injection pressure
- **Slightly higher BSFC at higher speed**
 - insufficient injection pressure
 - poor injection quality

Engine Test Summary - emissions

- **Lower NOx**
 - lower premixed burn
 - lower peak cylinder pressure (lower max in-cylinder temperature)
- **Higher PM**
 - lower injection pressure
 - later injection event
 - poor injection quality

Future Work in the Following Areas:

- **Piezoelectric Materials**
- **Actuator Design**
- **Motion Amplification**
- **Voltage Amplification**
- **Controls Approaches**