Recent Activity for Brake Wear Particle Emission Measurement using JARI System

Hiroyuki Hagino
Japan Automobile Standards Internationalization Center (JASIC)
Overview

Emission level under new PMP test cycle using JARI system

JARI system improvement scheme for PN measurement system

Interlaboratory testing with JSAE collaboration

Conclusions and Next Steps
What we want to Measure and How?

- PMP: Propose Common Methodologies (Technologies) for PN and PM
- JSAE / JARI:
  - Most Common Methodology → Wear Mass Measurement
  - Important: Most Comparable Methodology → Wear Mass vs ???

Air Quality Improvements

Ex.) Brake Design

Brake Emission (PN, PM)

Wear Mass (Wear Pad + Wear Rotor)

Development Brake Design
- System, Rotor Aggression, Pad Wear, Friction Mechanisms
- (Loose granular, Dens sheet, Oxidation, Gas cushion, Liquid lubrication...)

Control and Development

Comparability (Correlation)
Current Status JARI Measurement System

◆ Sampling System: **Storable in Pre-Exiting Dyno. and Bench** (JSAE 4 labs.)
  Visited to JSAE member labs. and Measured the Sizes.
◆ Compromise Necessary for **Sampling Efficiency**
◆ Incapable of Compromise for **Comparability of Emissions vs Wear**

**JARI Measurement System**

PM Measurement
Filter Sampling with Impactor (PM$_{10}$, PM$_{2.5}$)
Filter: PTFE 47φ
Sampling: 20L/min

PN Measurement
Fine Particles:
CPC without pre-treatment
Coarse Particles:
APS without pre-treatment

Pull  \[\rightarrow\]  Particle Sampling  \[\leftarrow\]  Push
Particle Free Air
25±5°C, RH50±10%

Dyso.  \[\rightarrow\]  Enclosure  \[\leftarrow\]  HEPA Filter
HV Sampler
Sampling Probes
Challenges for Common Technology

◆ Common Challenges: Comparability with Emission and Wear (Dust, Pad & Rotor life)
◆ Common Technology: Constant Flow Sampling and Validations, so How?

Sampling Efficiency

- Particle Depositions on Brake Systems
  - Caliper in-side
  - Brake Pad Surface
- Compromise Necessary!!

Air Flow

- PM & PN survey in JARI
  - Review on Test Results under Low Air Flow Rate during JC08, WLTC, NEDC, PMP
  - Ex.)
- PM vs Wear Mass
- PN vs Wear Mass

System Validations

- Only PM survey in JARI / JSAE
  - Interlaboratory Testing with Same Brake Systems, Same Sampling Systems, Preexisting Dyno.

Uniformed Design

- JARI / JSAE

Quality Assurance (QA)

- Sampling Efficiency Testing focused on Chamber & Tunnel using PSL (0.002~10 um)

Modified System

- JARI / JSAE
  - Effective-Cooling / Wall-Loss-Less Modification

Modified System

- JASO Standardization for PM with comparable PN measurements
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Emission Levels vary in Different Driving Cycles

- Good Correlation with PN and PM emission during Same Driving Cycle
- but Slope (PN/PM Factor) might be changed by Particle Size and Brake Pad

**PM$_{10}$ Emission Levels**

**PN Emission Levels (only CPC meas.)**
Need Comparability PM, PN, and Wear Mass

- Good Correlation with PM and Wear Mass emission under Different Driving Cycles with Same NAO/LS Brake
- Nature of Particle Emission might be quite different between PN and PM

**PM$_{10}$ vs. Wear Mass (Pad + Rotor)**

<table>
<thead>
<tr>
<th>PM$_{10}$</th>
<th>Wear Mass</th>
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<tbody>
<tr>
<td>NAO</td>
<td>7</td>
</tr>
<tr>
<td>LS</td>
<td>6</td>
</tr>
<tr>
<td>NEDC</td>
<td>5</td>
</tr>
<tr>
<td>PMP</td>
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**PN vs. Wear Mass (Pad + Rotor)**

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<td>JC08</td>
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**PM$_{10}$ vs. Brake Temp. ($\propto$ Brake Energy)**

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<tr>
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<th>Brake Temp.</th>
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<tbody>
<tr>
<td>NAO</td>
<td>140</td>
</tr>
<tr>
<td>LS</td>
<td>130</td>
</tr>
<tr>
<td>NEDC</td>
<td>120</td>
</tr>
<tr>
<td>PMP</td>
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Comparability PM and PN

◆ Brake Wear Particle Emissions during NEDC cycle
◆ Good correlation between PM10 and total PN (e.g. CPC and APS),
◆ Due to PM and PN Compatibility, PN (10nm-10μm) measurement is highly recommended

Ref.: Hagino et al., in preparation
Brake Wear Particle Morphology

- Coagulation Small Particles (Adhesion on Particle) allowed
- Is it enough to measure coarse PN for obtaining good correlation with PM?
- Coarse (Large) PN measurement needs to manage
  Fibrous particles (Materials) tends to be detected in the Larger Size

Ref.: Hagino et al., in EuroBrake2018
Ref.: Eggenschwiler and Schreiber in PMP session 47
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Why we need modify Air Flow for PN?

- **PM measurement: Robust System** under Low Air Flow
- **PN measurement: High Sensitive System** for High Air Flow
- **JARI system Observed ...**
  Over concentration (> $10^5$ #/cm$^3$ for typical CPC (CPC3750 (>7nm)))
  Nozzle Warm (Clogging of Orifice by Large Size Particles)
  Pulse Height Error (Butanol Back Current by Clogging of Orifice)

**Necessary of more Air Flow to Obtain Robust Optimization**
Needed for using Cyclone (Removing for Large Particles) for CPC Measurement

**Ex.) Repeat Test using PMP cycle**

![Graph showing PM and PN measurements over different runs.](graph.png)

- **Run1** NAO
- **Run2, Run3**
- **Run4** LS
- **Run5, Run6**

**PM [mg/km/veh.]**
- Run1: 5
- Run2: 4
- Run3: 4
- Run4: 7
- Run5, Run6: 5

**PN [#/km/veh.]**
- Run1: 4.5E+07
- Run2: 4.0E+07
- Run3: 3.5E+07
- Run4: 3.0E+07
- Run5, Run6: 2.5E+07

**Pulse Height Error**
Modification of Air Flow for PN

- PMP cycle is Much Higher Sampling Temperature than NEDC
- Sampling Temperature might have to be set for conventional CPC (< 35 °C)

![Graph showing Sampling Temperature vs Air Flow Rate]

Q = \frac{60 \times q}{\rho \times C_p \times \Delta T}

- q : Calorific value [W]
- \Delta T : Difference temp. (In/Sampling) [K]
- \rho : Air Density, 1.20 [kg/m³]
- C_p : Isobaric Specific Heat, 1007 [J/(kg/K)]
- Q : Air Flow [m³/min]
Modification of Air Flow for PN

◆ Change Air Supply for Higher Air-Velocity and Lower Chamber Wall-Loss

4 m³/min : 150A with Same Isokinetic Sampling Probe (SUS 316L Electro Polish)

1 m³/min : 80A

Attachment of Apparatus for Higher Air-Velocity and Lower Chamber Wall-Loss
Labs. Difference vs. Air Flow Rate

- Air Flow Rate may be contribute for High Uncertainties of Instruments
- High Volume Filter Sampling (1 m³/min) is using worldwide
- JARI system was applied the compatibility Sampling, but adjustable by 5 m³/min

High Uncertainty Region for the Instruments

PM: 0.01 mg/m³
PN: 10² #/cm³

Cycle: simulated-WLTC, 30 Repeated, PM data: DustTrak II 8530 corrected by gravimetric measurement, PN data: TSI CPC 3775 (D₅₀ = 4 nm) without pretreatment

Ref: Hagino et al., EuroBrake 2018 in Presentation, revised.
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Comparison of Brake Wear Testing

- On-going project: Comparison of PM Emission (NEDC and PMP cycles)
- Existing Dynamometers
- Wear Mass: for More High Reproductivity,
  **Actual Brake Torque might be need to Control**
- Rotor/Brake Wear Mass and Temp. did not affected by Lower Flow Rate Condition

![Graph showing wear mass and brake temperature](chart.png)

**[Testing Conditions]**
Pre-conditioning: Initial Speed 65km/h, Deceleration 3.5m/s², 200 times (or more for NAO discs) repeated,
Vehicle: Weight 1,130kg, Ratio 8:2, Eff. Tire Rad. 0.298m,
Brake Systems: NAO Disc (Front) / LS Disc (Front),
Test Cycle: NEDC (JARI Emission Testing), 30 times Repeated

Ref: Hagino et al., *Wear & EuroBrake2018 in Preparation*
Conclusions:

• Good Correlation with PM and Wear Mass emission
• Nature of Particle Emission might be quite different between PN and PM
• Due to PM and PN Compatibility, PN (10nm-10µm) measurement is highly recommended
• PN measurement needs further investigation
• Inter-lab. Testing of Wear Mass
  Needing of Actual Brake Torque Control

Next Steps:

• Modification of Air Flow for PN measurement using JARI/JSAE system (On-going)
• Reproducibility of PM Emissions with Uniformed Sampling Design with JSAE Four Labs. (On-going)