Submission ID #: 61287
Scriptwriter Name: Bridget Colvin
Project Page Link: https://www.jove.com/account/file-uploader?src=18692583

Title: Measuring Sub-23 Nanometer Real Driving Particle Number Emissions Using the Portable DownToTen Sampling System

Authors and Affiliations: Markus Bainschab[1], Lukas Landl[2], Jon Andersson[3], Athanasios Mamakos[4], Stefan Hausberger[2], and Alexander Bergmann[1]

[1]Graz University of Technology, Institute of Electrical Measurement and Sensor Systems
[2]Graz University of Technology, Institute of Internal Combustion Engines and Thermodynamic
[3]Ricardo UK Ltd., Shoreham-by-Sea, United Kingdom
[4]AVL List GmbH

Corresponding Author:
Markus Bainschab
m.bainschab@tugraz.at

Co-authors:
landl@ivt.tugraz.at
jon.andersson@ricardo.com
Athanasios.Mamakos@avl.com
hausberger@ivt.tugraz.at
alexander.bergmann@tugraz.at

Author Questionnaire

1. Microscopy: Does your protocol involve video microscopy, such as filming a complex dissection or microinjection technique? **N**

2. Software: Does the part of your protocol being filmed demonstrate software usage? **Y**

If **Yes**, we will need you to record using screen recording software to capture the steps. If you use a Mac, QuickTime X also has the ability to record the steps. Please upload all screen captured video files to your project page by the script return deadline

Videographer: screen captures not provided, please film

3. Filming location: Will the filming need to take place in multiple locations (greater than walking distance)? **N**

Protocol Length

Steps: **56**

Introduction

1. Introductory Interview Statements

REQUIRED:

1.1. **Markus Bainschab**: This protocol can be used to acquire a mobile measurement of currently unregulated sub-23-nanometer particle emissions using a system that was designed and constructed in the H2020 project DownToTen **[1]**.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

REQUIRED:

1.2. **Lukas Landl**: Low particle losses in the sub-23-nanometer regime of interest and the high degree of versatility within the system enable assessment of the different properties of the emitted particles **[1]**.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

OPTIONAL:

1.3. **Athanasios Mamakos**: With exception to the exhaust emissions, this method would be ideal for investigation of the volatility and formation mechanisms of nano-sized brake-wear particles **[1]**.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Videographer: Can cut for time*

Protocol

2. Exhaust Flow Meter (EFM) Installation

2.1. Begin by selecting an exhaust flow meter with a measurement range matching the expected exhaust flow range of the vehicle to be measured **[1]**.

2.1.1. WIDE: Talent selecting EFM

2.2. Place the exhaust flow meter control box in the trunk of the vehicle **[1]** and install the exhaust flow meter on the outside of the car according to the manufacturer's specifications **[2]**, taking care that the distance upstream and downstream of the meter comply with federal regulations **[3]**.

2.2.1. Talent placing control box into trunk OR Shot of control box in trunk

2.2.2. Talent installing EFM onto car OR Shot of EFM on car

2.2.3. Talent checking distances

2.3. Check that the connectors from the exhaust flow meter pipe to the exhaust pipe of the vehicle can withstand the exhaust gas temperatures **[1-TXT]**.

2.3.1. Talent checking connectors **TEXT: Pipe, connector, and extension diameters > exhaust pipe diameter to maintain low exhaust back pressure**

2.4. When the exhaust flow meter has been installed, use connecting pipes and pipe clamps to connect the exhaust to the first pipe **[1]**, tightening the pipe clamps at the end only to facilitate alignment of the pipes during the fitting **[2]**.

2.4.1. Talent connecting pipe to exhaust *Videographer: Important step*

2.4.2. Talent tightening pipe clamp *Videographer: Important step*

2.5. When there is a connection from the exhaust to the exhaust flow meter, place the exhaust flow meter control box and the exhaust flow meter mounting bracket into the trunk to ensure that nothing slips during the measurement trip **[1]** and check that all of the piping is tight and that nothing will come loose during the measurement trip **[2]**.

2.5.1. Talent placing box and bracket into trunk

2.5.2. Talent checking piping connections

2.6. After a warmup time of up to 15 minutes depending on ambient temperature, the exhaust mass flow meter is ready to take measurements **[1]**.

2.6.1. Talent warming up EFM

3. DownToTen (DTT) Measurement System Preparation and Installation

3.1. To install the Down to Ten measurement system, place the synthetic air bottle into the trunk **[1-TXT]** and fix the bottle in place with straps **[2]**.

3.1.1. WIDE: Talent placing bottle into trunk **TEXT: Alternative: Place bottle on floor in front of rear seats**

3.1.2. Talent fixing bottle with straps

3.2. Place the battery into the trunk of the vehicle **[1]** and plug in the AC input cable **[2]**.

3.2.1. Talent placing battery into trunk

3.2.2. Talent fixing battery with straps NOTE: Show 3.3.1 before 3.2.2

3.3. Fix the battery in place **[1]** and connect the AC cable to a local power source **[2]**.

3.3.1. Talent plugging AC input cable into battery

3.3.2. Talent connecting cable to power source

3.4. Fix the vacuum pumps for the sampling system and the condensation particle counters in the trunk of the vehicle **[1]** and connect the pumps to the battery **[2]**.

3.4.1. Talent fixing pumps in trunk

3.4.2. Talent connecting pumps to battery

3.5. Next, place the Down to Ten system in the trunk of the vehicle **[1]** and fix its position with straps **[2]**.

3.5.1. Talent placing system into trunk

3.5.2. Talent fixing system with straps

3.6. Connect the system to the mobile battery pack **[1]** and connect the two inlet mass flow controllers of the Down to Ten system to a stationary pressurized air supply **[2]**.

3.6.1. Talent connecting system to battery pack

3.6.2. Talent connecting MFC to stationary pressurized air supply

3.7. Connect the two outlet mass flow controllers of the Down to Ten system to the vacuum pump **[1]** and use the appropriate tubing to drive the exhaust of the pump outside of the vehicle **[2]**.

3.7.1. Talent connecting MFC to vacuum pump *Videographer: Important step*

3.7.2. Talent connecting tubing for driving exhaust *Videographer: Important step*

3.8. Use a USB cable to connect the Down to Ten system to the measurement laptop **[1]** and connect the inlet of the system to the sampling point downstream of the exhaust flow meter **[2]**.

3.8.1. Talent connecting cable to laptop

3.8.2. Talent connecting inlet to sampling point

3.9. Connect the system power inlet to the battery **[1]** and connect the condensation particle counter power inlets to the battery pack **[2]**.

3.9.1. Talent connecting system power inlet to battery

3.9.2. Talent connecting condensation particle counter power inlets to battery pack

3.10. Connect the condensation particle counters to the respective external vacuum pump **[1]** and use appropriate tubing to drive the exhaust of the condensation particle counter and/or the external pump outside of the vehicle **[2]**.

3.10.1. Talent connecting CPCs to pump *Videographer: Important step*

3.10.2. Talent connecting tubing to drive exhaust *Videographer: Important step*

3.11. Then use a USB cable to connect the condensation particle counters to the measurement laptop **[1]**.

3.11.1. Talent connecting CPCs to laptop

4. Measurement Operation

4.1. To heat and start up the measurement system, switch on the condensation particle counters and their external vacuum supply **[1]** and open the condensation particle counter software **[2]**.

4.1.1. WIDE: Talent turning on CPCs and/or vacuum supply

4.1.2. Talent opening software, with monitor visible in frame

4.2. Establish communication with the condensation particle counters **[1]** and close the needle valves of the mass flow controllers **[2]**.

4.2.1. SCREEN: To be provided by Authors: Communication being established

4.2.2. Talent closing needle valve(s)

4.3. Next, push the red switch of the Down to Ten sampling system pump to turn on the system **[1]** and open the LabVIEW Down to Ten application **[2]**.

4.3.1. Talent pushing switch

4.3.2. Talent opening application, with monitor visible in frame

4.4. The communication with the system will start automatically **[1]** and the graphical user interface will display the flow in and out at dilution stages 1 and 2 **[2-TXT]**.

4.4.1. SCREEN: To be provided by Authors: Communication starting

4.4.2. SCREEN: To be provided by Authors: Shot of flow in and flow out **TEXT: If dilution stages do not equal 0.00 L/min, double check needle valve closure**

4.5. Enter the mass flow drawn by the connected measurement instruments in standard liters/minute **[1-TXT]** and slowly open the needle valves **[2]** until both “flows out” reach 10 plus or minus 0.5 standard liters/minute **[3]**.

4.5.1. SCREEN: To be provided by Authors: Mass flow being entered **TEXT: If mass flow unknown, measure with handheld mass flow meter**

4.5.2. Valve(s) being opened

4.5.3. SCREEN: To be provided by Authors: Flows out approaching/in reading 10 ± 0.5 sL/min

4.6. Adjust the "Add Flow" of both dilution stages so that the flowrate in the catalytic stripper is equal to 1 plus or minus 0.1 liter/minute through the catalytic stripper and a sample inlet flow of catalytic stripper sample flow rate equals 1 plus or minus 0.1 liter/minute **[1]**.

4.6.1. SCREEN: To be provided by Authors: Add flow(s) being adjusted

4.7. Under the **Heater** tab, set the heater temperatures of the dilution air supply, the first porous tube diluter, and the catalytic stripper to 350 degrees Celsius. The system will begin to heat up **[1]**.

4.7.1. SCREEN: To be provided by Authors: Heater tab being selected, then temperatures being set *Video Editor: please emphasize current temperature and heating power percentages below Set interfaces with “system will begin to heat up”*

4.8. Then wait until the gas temperature downstream dilution stage 1 reaches 290 degrees Celsius before starting the measurement drive **[1]**.

4.8.1. SCREEN: To be provided by Authors: Temperature downstream dilution stage 1 reaching 290 degrees

5. Data Logging

5.1. To log the data, on the measurement device connected to the Down to Ten sampling system, click **Start Data Logging** to start to log the data of the sampling system **[1]** and select a path and a file name in the pop-up window **[2]**.

5.1.1. WIDE: Talent clicking start data logging, with monitor visible in frame

5.1.2. SCREEN: To be provided by Authors: Path being selected and file name appearing

5.2. The log file path will be displayed, and the green light will indicate that the data are saved **[1-TXT]**.

5.2.1. SCREEN: To be provided by Authors: Log file path and green light being displayed **TEXT: Data logged at 2 Hz frequency**

5.3. Then use the appropriate software to log the particle concentration data of the condensation particle counter **[1]** and start logging the exhaust flow with the exhaust flow meter **[2]**.

5.3.1. SCREEN: To be provided by Authors: Particle concentration data being logged in software

5.3.2. SCREEN: To be provided by Authors: Exhaust flow being logged with EFM OR Exhaust flow being logged with EFM

5.4. To log the data while driving, before driving the selected route, disconnect the battery charging cable **[1]** and switch from stationary pressurized air supply to the gas bottle **[2]**.

5.4.1. Talent disconnecting battery charging cable

5.4.2. Talent switching to gas bottle

5.5. Then drive the selected route **[1]**.

5.5.1. Talent getting into car or Talent sitting at steering wheel, putting on seat belt or turning key in ignition or similar representative action

5.6. After driving, press **Logging** to stop recording the data **[1]** and shut down the instruments **[2]**.

5.6.1. Talent pressing logging, with monitor visible in frame

5.6.2. Talent shutting down instruments

5.7. Then recharge the battery to prepare for the next drive **[1]**.

5.7.1. Talent charging battery

Protocol Script Questions

A. Which steps from the protocol are the most important for viewers to see?

2.4., 3.7., 3.10.

B. What is the single most difficult aspect of this procedure and what do you do to ensure success?

n/a

Results

6. Results: Representative Particle Penetration and Particle Number Emission Analyses

6.1. Here an exemplary plot of the relative particle penetration of the Down to Ten system as a function of the particle mobility diameter is shown **[1]**.

6.1.1. LAB MEDIA: Figure 11

6.2. The thermophoretic **[1]**, diffusional **[2]**, and total loss data **[3]** were plotted to determine the respective particle size dependencies **[4]**.

6.2.1. LAB MEDIA: Figure 11 *Video Editor: please emphasize orange dashed line*
6.2.2. LAB MEDIA: Figure 11 *Video Editor: please emphasize green dashed line*
6.2.3. LAB MEDIA: Figure 11 *Video Editor: please emphasize red data line*
6.2.4. LAB MEDIA: Figure 11

6.3. In this analysis, the diffusivity rising with the lower particle size **[1]** made this the dominant loss mechanism for particles less than or equal to 10 nanometers **[2]**.

6.3.1. LAB MEDIA: Figure 11 *Video Editor: please emphasize green data line*
6.3.2. LAB MEDIA: Figure 11 *Video Editor: please emphasize green data line from 0-10 dp/nm*

6.4. The total penetration efficiency is also represented **[1]**, allowing determination of the particle size at which the penetration efficiency amounts to 50% **[2]**.

6.4.1. LAB MEDIA: Figure 11 *Video Editor: please emphasize purple dashed data line*
6.4.2. LAB MEDIA: Figure 11 *Video Editor: please add/emphasize brown vertical and horizontal lines*

6.5. Here the particle number emission rate over time for the first ten minutes of a real drive emissions measurement drive is shown **[1]**.

6.5.1. LAB MEIA: Figure 12 upper graph

6.6. Sharp downward pointing spikes in all three of the signals occurred because the particle measurement devices can report zero particle concentrations temporarily and zeros cannot be displayed in logarithmic plots **[1]**.

6.6.1. LAB MEIA: Figure 12 upper graph *Video Editor: please emphasize downward pointing spikes*

6.7. The particle emissions measured with the 10-nanometer condensation particle counter **[1]** were very close to the emissions measured with the 23-nanometer condensation particle counter for the majority of the measurement period **[2]**.

6.7.1. LAB MEDIA: Figure 12 upper graph *Video Editor: please emphasize orange data line*

6.7.2. LAB MEDIA: Figure 12 upper graph *Video Editor: please emphasize blue data line*

6.8. However, between 10 and 25 seconds there was an occurrence of significant less than 23-nanometer particle emission **[1]**, as in this analysis, greater than 50% of the total number of particles emitted were between 10 and 23 nanometers **[2]**.

6.8.1. LAB MEDIA: Figure 12 upper graph *Video Editor: please emphasize red dashed rectangle*

6.8.2. LAB MEDIA: Figure 12 upper graph

Conclusion

7. Conclusion Interview Statements

7.1. **Lukas Landl**: When attempting this procedure, it is important to remember to properly install the exhaust flow meter and to provide sufficient warmup time for the sampling system [**1**].

7.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera (2.3., 3.1.)

7.2. **Athanasios Mamakos**: The versatility and low losses of the DownToTen system make it an ideal tool for the investigation of nonregulated particle emission, such as brake-wear and total exhaust particles **[1]**.

7.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Videographer: Can cut for time*

7.3. **Markus Bainschab**: This system and method were used in the H2020 project DownToTen to assess sub-23-nanometer particle emission of a variety of vehicles to provide a scientific basis for future emission regulations **[1]**.

7.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Videographer: Can cut for time*