



YOUR DEVELOPMENT PARTNER

WLTP Cycle for brake dust emissions with various particle measurement techniques

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01_ IDIADA's Involvement in Brake Emissions Study

02_ Brake Dynamometer Set-up

03_ Testing Procedures

04_ Test Data Analysis and Results

05_ Technical conclusions

06_ Next Steps

⊕ Current activities:

- Constant involvement in the PMP Working Group:
 - Updated on the industry progress and procedures definition
 - PMP sessions assistance and follow-up
 - Future Task Force involvement

- Brake Dynamometer bench ready to be used:
 - IDIADA UK facilities
 - Sampling box designed, manufactured and installed
 - Collection and analysis equipment
 - Brake WLTP cycle reproduced
 - Brake parts purchased for the testing



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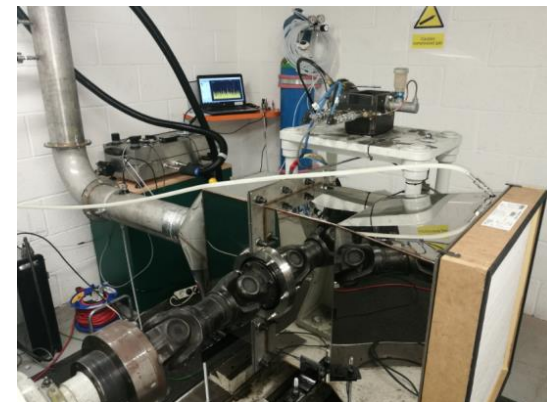
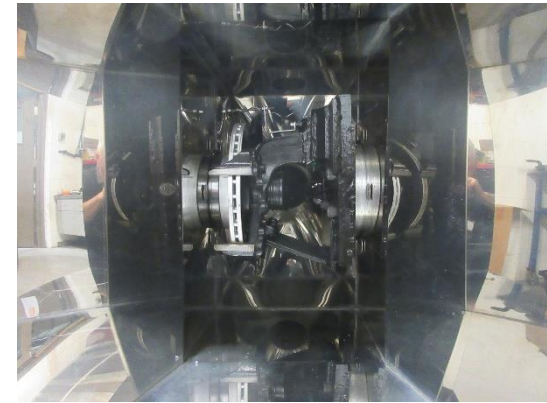
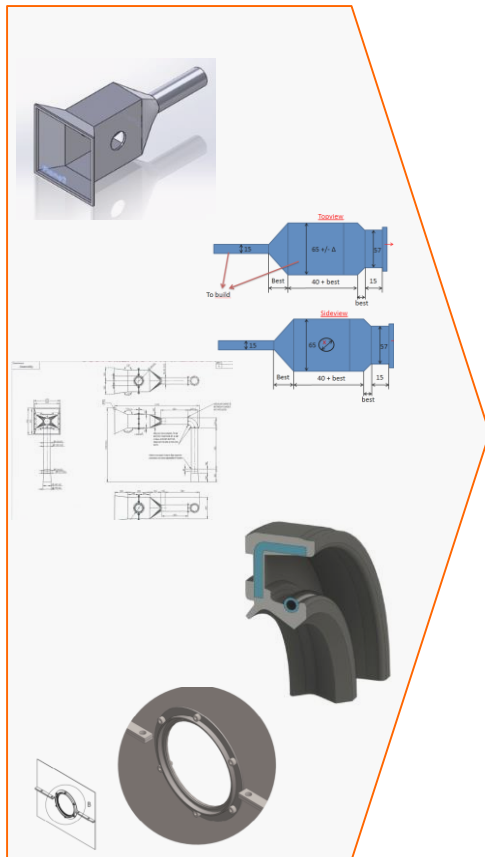
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Set-up and Chamber Conditioning

After all the previous tasks, the instrumentation and the measurement systems installation, the final set-up of the PC3 was made:



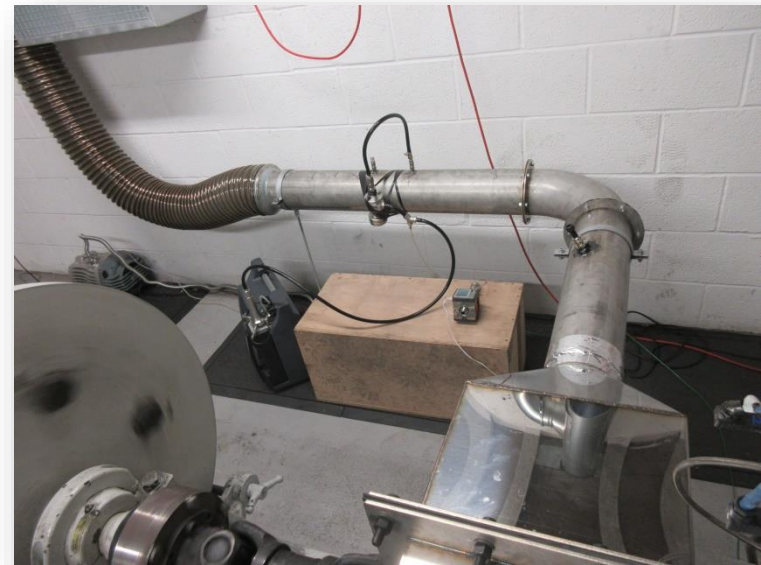
Set-up and Chamber Conditioning

Different methods assessed for extraction air set-up & particles flow:

VERTICAL EXTRACTION



HORIZONTAL EXTRACTION



Data Acquisition System (1st Campaign)

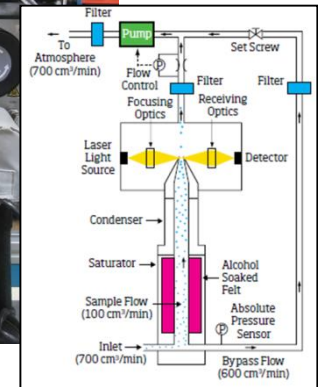
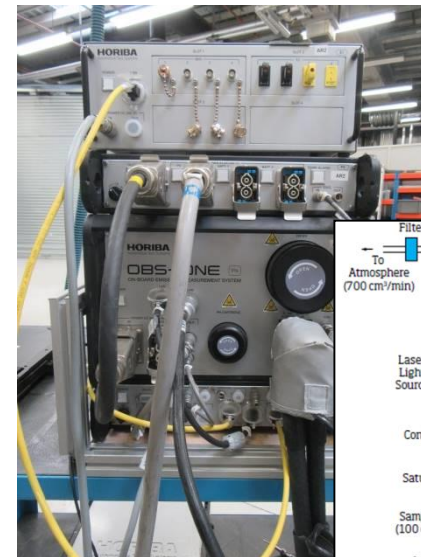
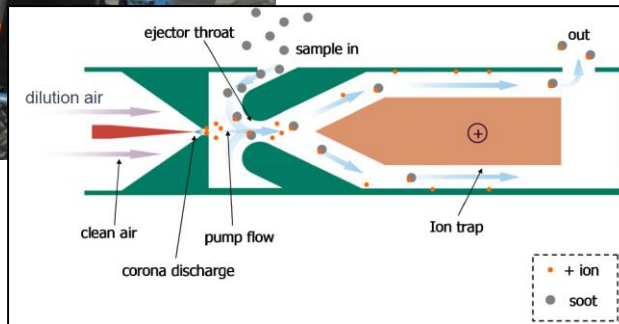
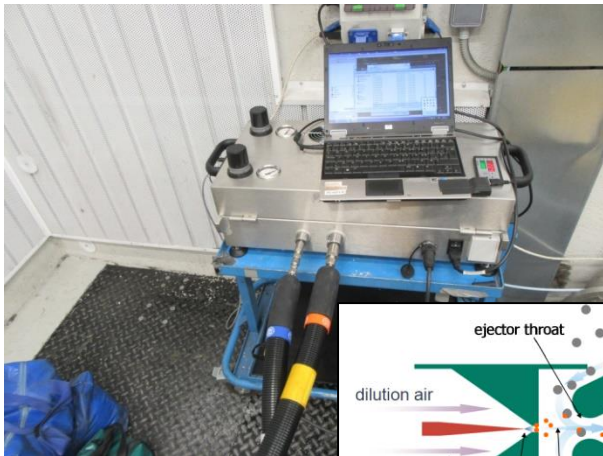
Two different emissions measurement equipment were brought to the PC3 dyno for analysis studies:

PEGASOR

- ⊕ Pegasor Particle Sensor is a real-time continuous detector for PM measurements. The sensor inside reports total surface area, mass and total number of particles. Capable to detect particles **up to 2.5 μm** and the sample flow rate is **2.5 l/min**.

OBS-ONE PN23 nm (CPC technology)

- ⊕ Portable Emissions Measurement System that it normally uses for RDE testing but it was chosen because of its accuracy. It only measure PN concentration. The particle size range of the equipment is **from 23 nm up to 1 μm** and the sample flow rate is **0.7 l/min**.



TSI model 3007

Data Acquisition System (2nd Campaign)

DEKATI's equipments rent for the 2nd Testing Campaign to:

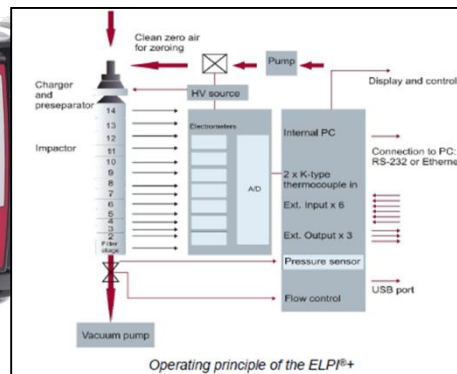
- Obtain PN and size distribution
- Get PM concentration throughout the cycles

HRELPI+ (PN measurement and size distributor)

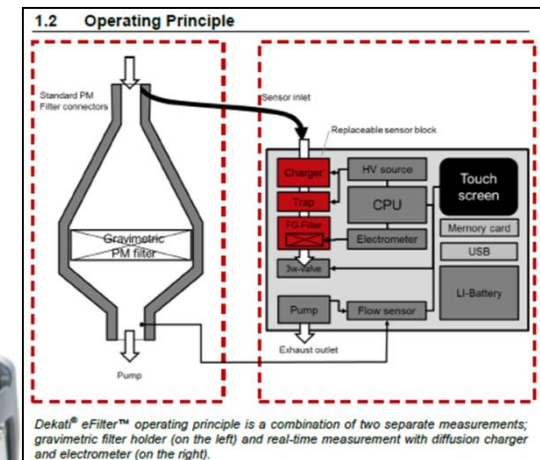
⊕ High Resolution Electrical Power Pressure Impactor (HRELPI+): Is a particle size spectrometer for real-time particle measurements. The ELPI®+ enables measurement of real-time particle size distribution and concentration in the **size range of 6 nm – 10 µm at 10 Hz** sampling rate. The sample flow rate of the equipment is **10 l/min**.

eFilter (Second-by-second PM measurement)

⊕ The eFilter combines a standard gravimetric filter holder and sensitive real-time PM detection in one compact instrument. This equipment has a secondary sample flow rate of **0.5l/min** and the size **upper cut-point is 3µm**.



Operating principle of the ELPI®+



Dekati® eFilter™ operating principle is a combination of two separate measurements; gravimetric filter holder (on the left) and real-time measurement with diffusion charger and electrometer (on the right).

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General considerations

❖ Brake system features

- ✓ Pads composition: Low steel
- ✓ Material status: Bedding done
- ✓ Brand/model: VW (segment C)

❖ Air flow rates

- ✓ High flow → 1100 m³/h
- ✓ Low flow → 600 m³/h

❖ Extraction air: Without air conditioning

❖ HEPA Filter: Class EN1822_H14 high flowrate 4000m³/hr

❖ Particle sampling

- ✓ Sample probe → 8 mm diameter with 4 x 2 mm orifices

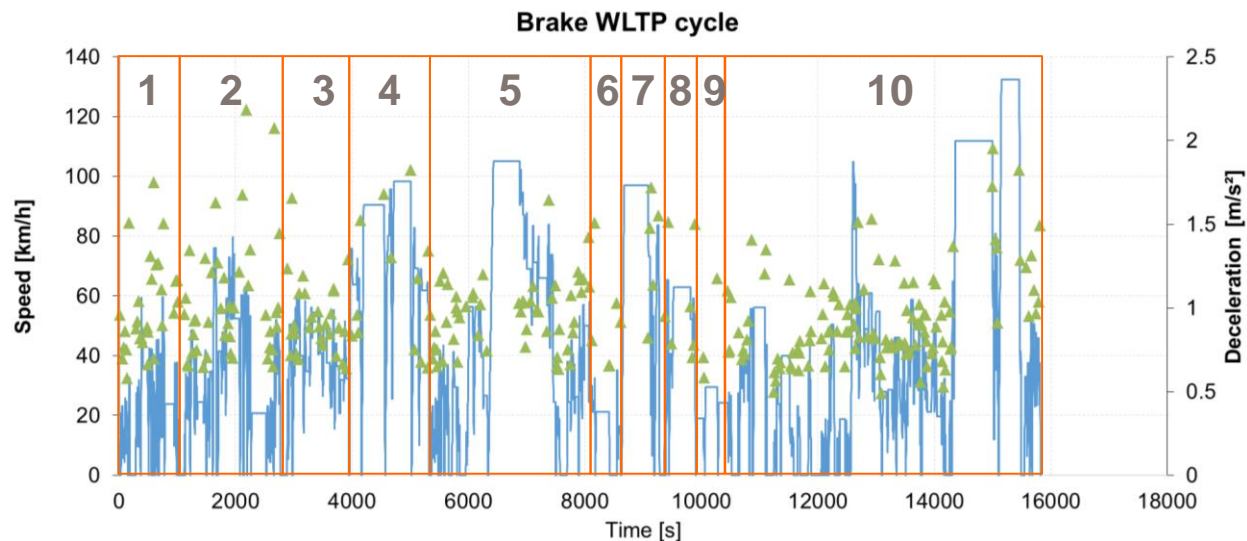


- ✓ Sample point (distance to extraction and to flowmeter):
 - Extraction: 3 x ID duct
 - Flowmeter: 4 x ID duct
- ✓ Sample tunnel (duct) diameter: 150 mm

WLTP Cycle adapted to brakes – Main features

PMP working group defined a Brake WLTP cycle for the brake particle emissions measurement: modification from the current exhaust emission test procedure.

- ⊕ 10 Phases
- ⊕ Soak times between phases
- ⊕ Effective cycle time = 15816 s (4.4h)
- ⊕ Total hours = 41h (PMP)
- ⊕ Total n° STOPS = 303



*Reference: "A novel real-world braking cycle for studying brake wear particle emissions". PMP paper

NOTE: The test takes almost 17h of duration, with some soak times included between test phases (IDIADA's brake dyno data)

Cycles defined for the testing campaign

The testing campaign was not focused on the repeatability of the results, but on the research and trying to understand the particles behavior. Hence, analysis focus on qualitative results rather than quantitative. The final tests to perform were:

#	Test	Description
1	WLTP “reduced”	<ul style="list-style-type: none"> Defined as the first two phases of the Brake WLTP cycle (“urban phases”)
2	WLTP “reduced” 2	<ul style="list-style-type: none"> Defined as the last phase of the original cycle (Phase 10 – “highway phase”)
3	Speed Effect	<ul style="list-style-type: none"> Particle behaviour during brake-off after a brake preconditioning and with different speeds
4	Off-brake tests	<ul style="list-style-type: none"> Running at different speeds (two different cycles defined)
5	Complete WLTP	<ul style="list-style-type: none"> Complete procedure of Brake WLTP
6	AK Master	<ul style="list-style-type: none"> Following standard test SAE J2522, fade sections performed

Investigation activities	
Box cleaning effect	<ul style="list-style-type: none"> Effect on the measures with cleaning tasks of the box between tests
Air flow effect	<ul style="list-style-type: none"> Differences related to air flow rate extraction (600 – 1100 m³/h)
Extraction layout	<ul style="list-style-type: none"> Vertical and horizontal extraction layout

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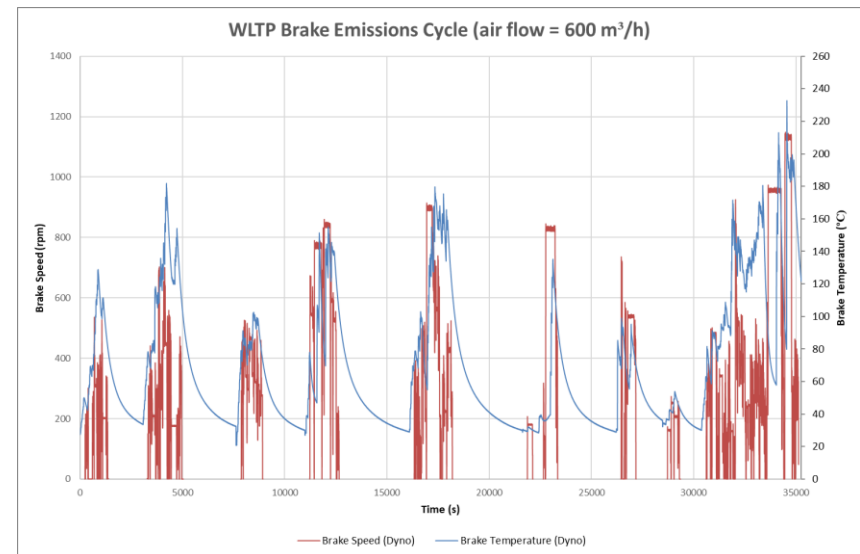
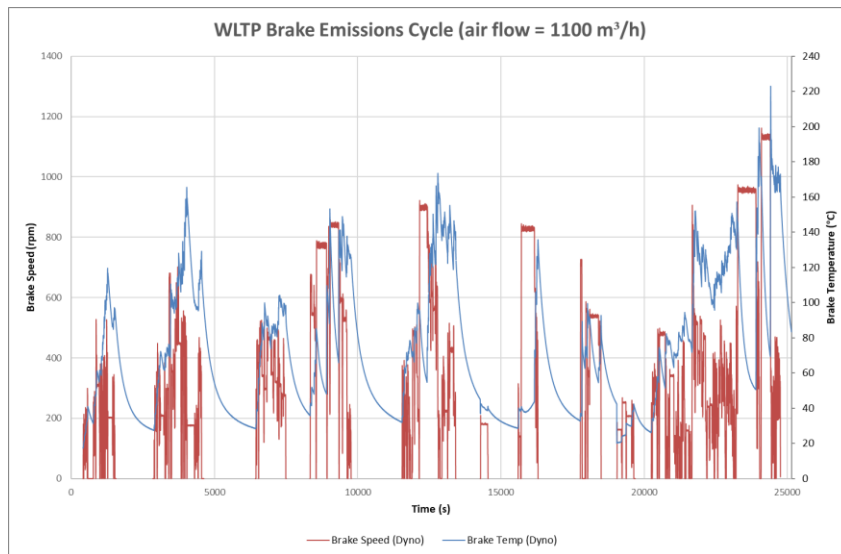
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Main Data Analysis (in progress)

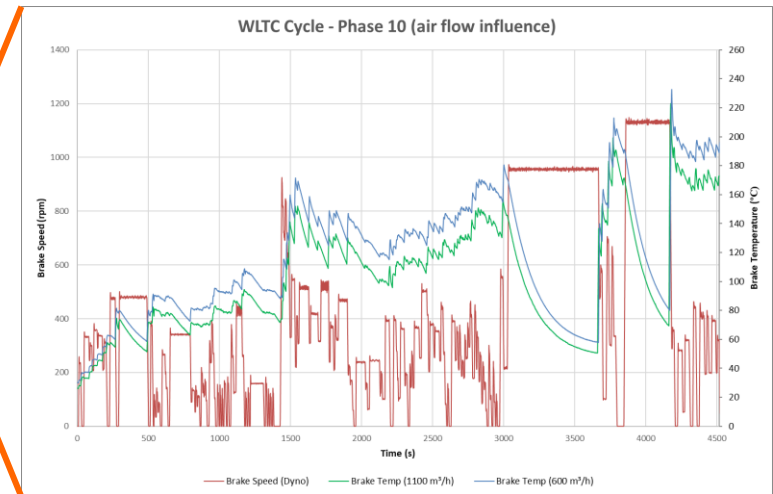
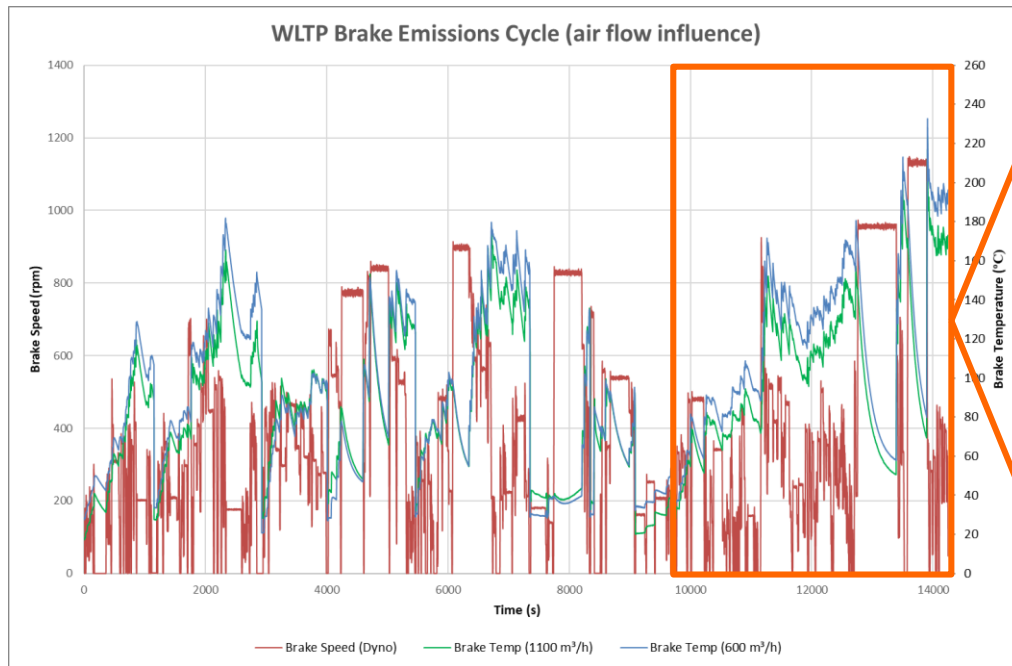
⊕ Speed and Temperature profiles of the WLTC Cycle



Brake temperatures are moderately affected by the flowrate range of 600 - 1100 m³/h. The total cycle time is increased with less flow.

Main Data Analysis (in progress)

- ⊕ Speed and Temperature profiles of the WLTC Cycle (Phase 10)

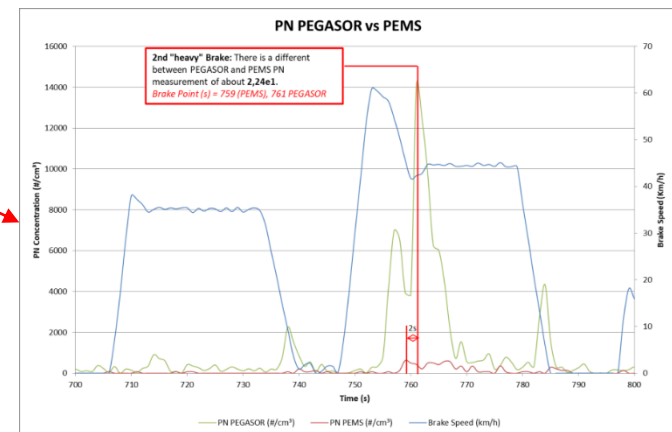
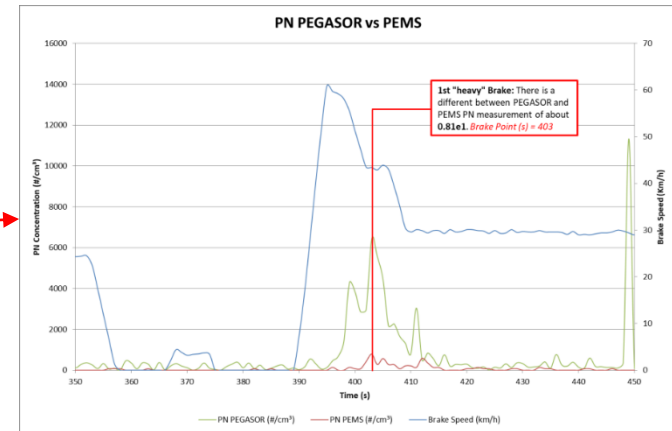
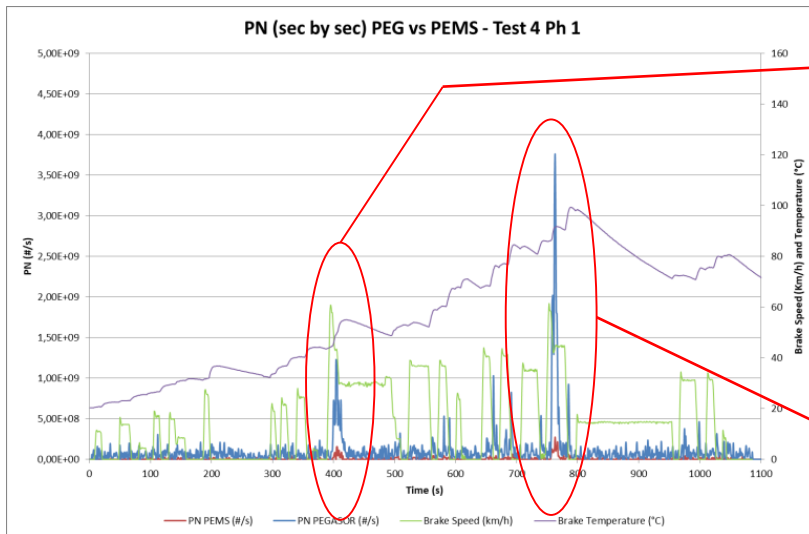


Brake temperatures differences within 20°C (Phase 10). Delta T is rather constant.

Main Data Analysis (in progress)

⊕ Data Acquisition Systems outputs comparison (PEMS-PEGASOR)

#/second



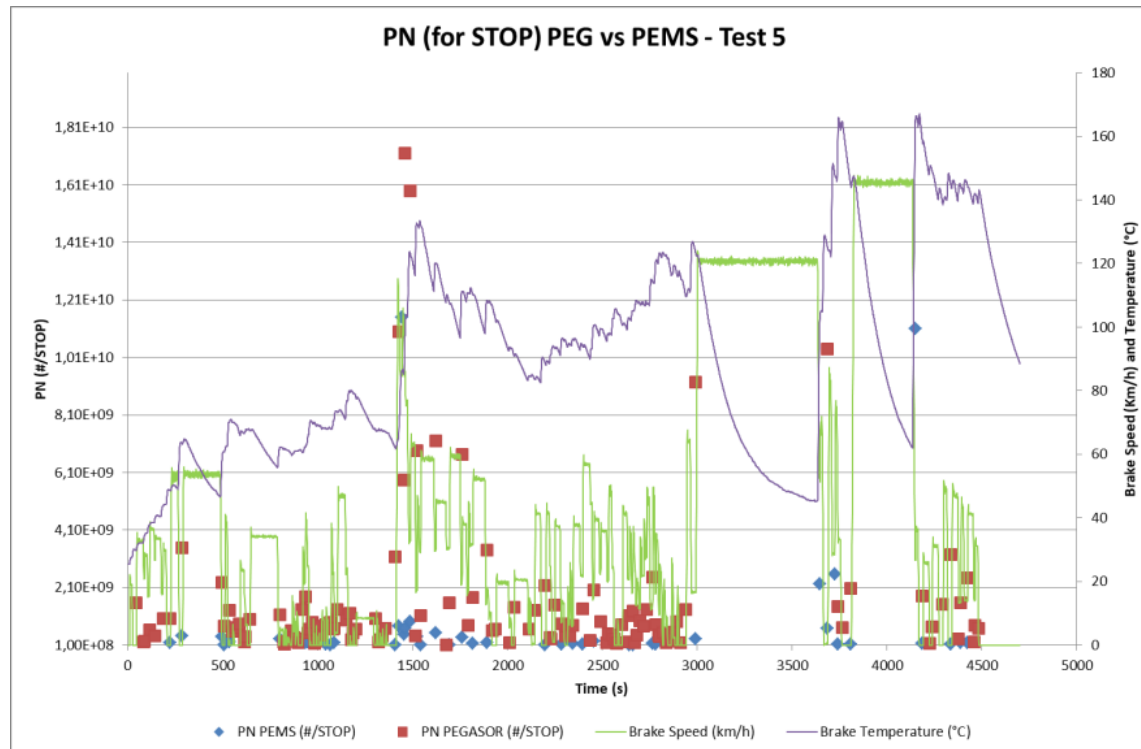
There is a difference between equipment of about one order of magnitude (PEGASOR results are always higher)

Main Data Analysis (in progress)

- ⊕ Data Acquisition Systems outputs comparison (PEMS-PEGASOR)

Phase 10

#/stop



NOTE: Two measurements hidden in the graph with values above 1.0E+11

Interesting way to see the PN emissions depending on the brake event.

Main Data Analysis (in progress)

⊕ Data Acquisition Systems outputs comparison (PEMS vs PEGASOR vs HRELPI)

- PMP studies results alignment (Brake-ON PN measurements)

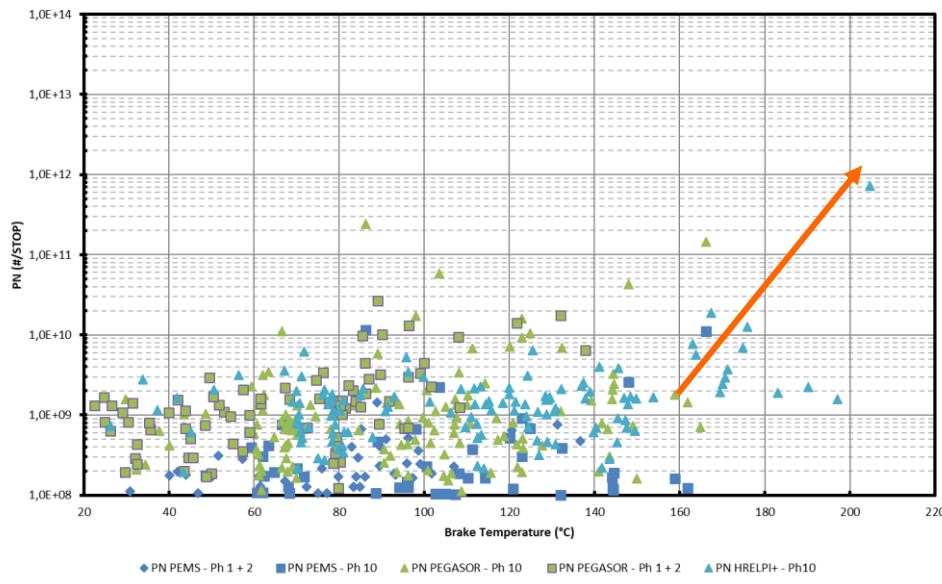
IDIADA Testing

- Devices: PEGASOR & PEMS PN23 & HRELPI+
- Air flow rate: 1100 m³/h
- Set up: IDIADA UK dyno (enclosed capture box)

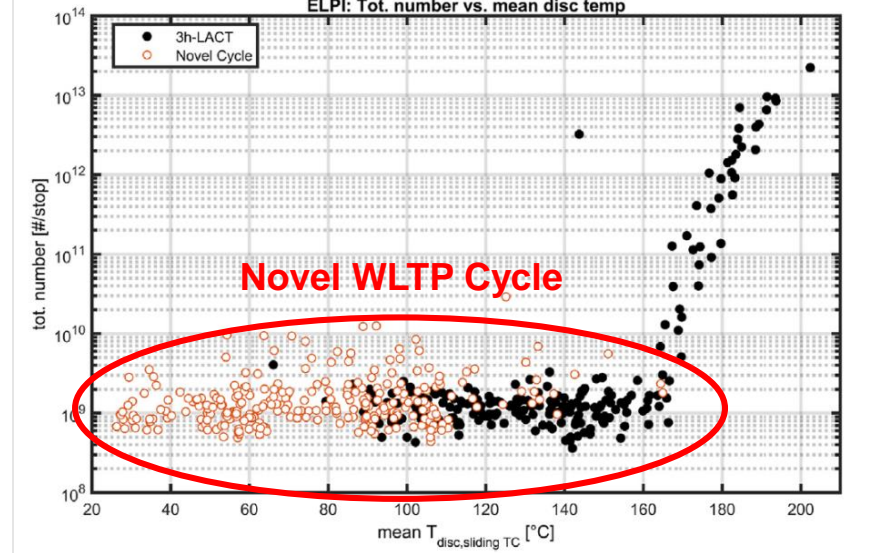
PMP paper results

- Device: ELPI+
- Air flow rate: 250 m³/h
- Set up: Ford dyno

PN (#/STOP) vs Brake Temperature (°C)



ELPI: Tot. number vs. mean disc temp

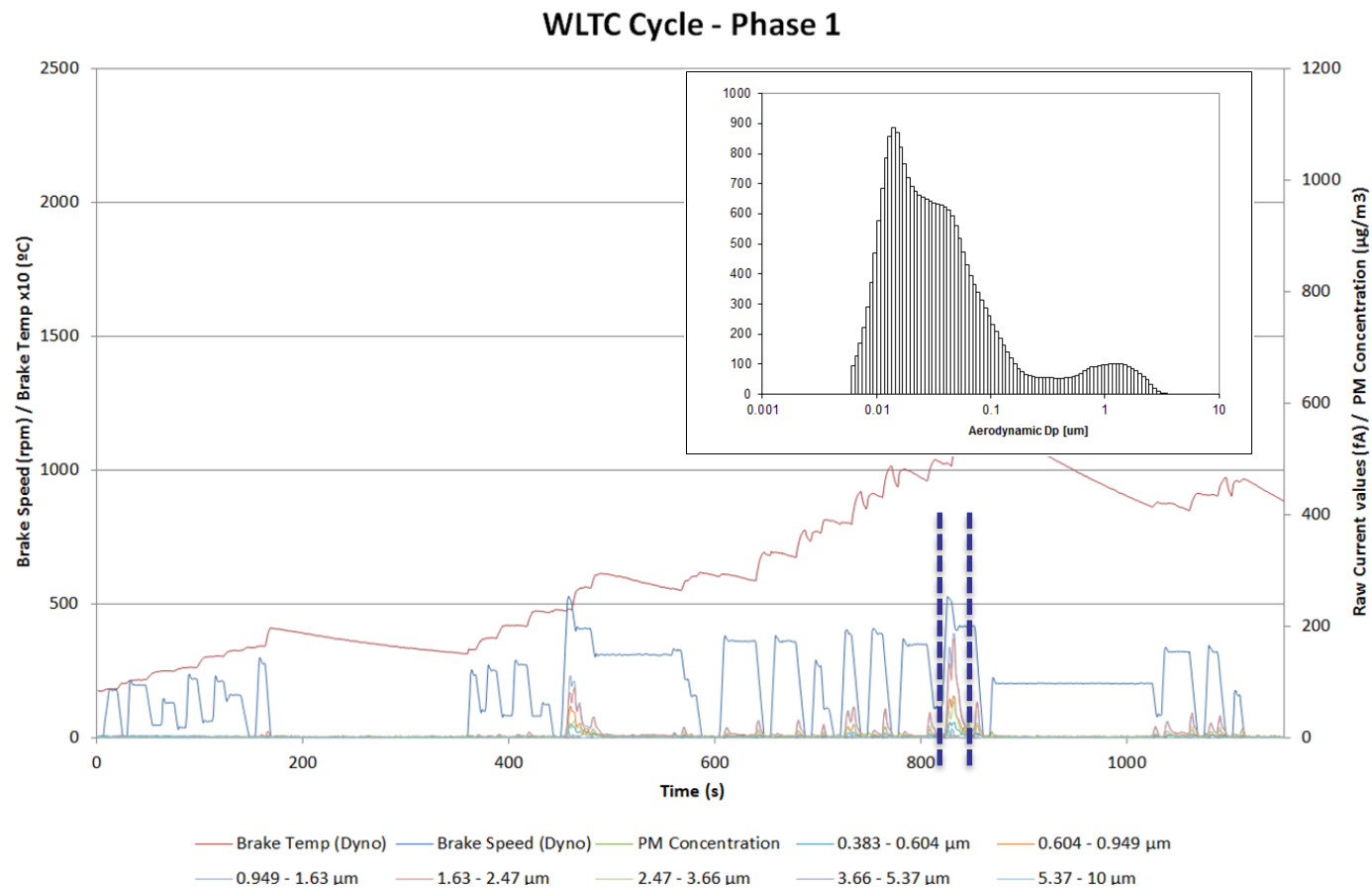


There is a **great similarity** between IDIADA's and PMP's results in the WLTP Cycle

Main Data Analysis (in progress)

⊕ HRELPI+ and eFilter data (1100 m³/h)

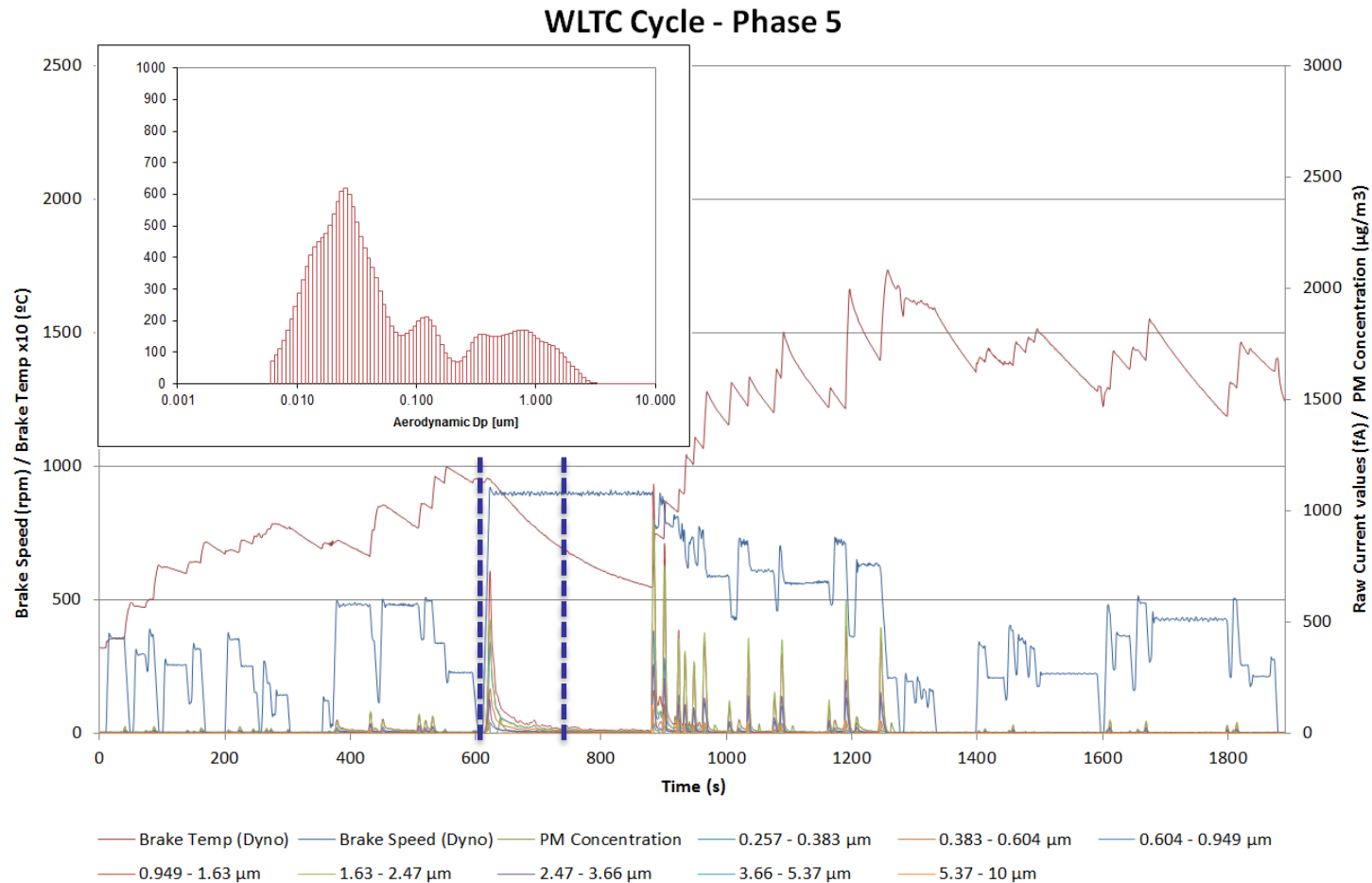
⊕ Phase 1 (WLTC Cycle)



Main Data Analysis (in progress)

⊕ HRELPI+ and eFilter data (1100 m³/h)

⊕ Phase 5 (WLTC Cycle)



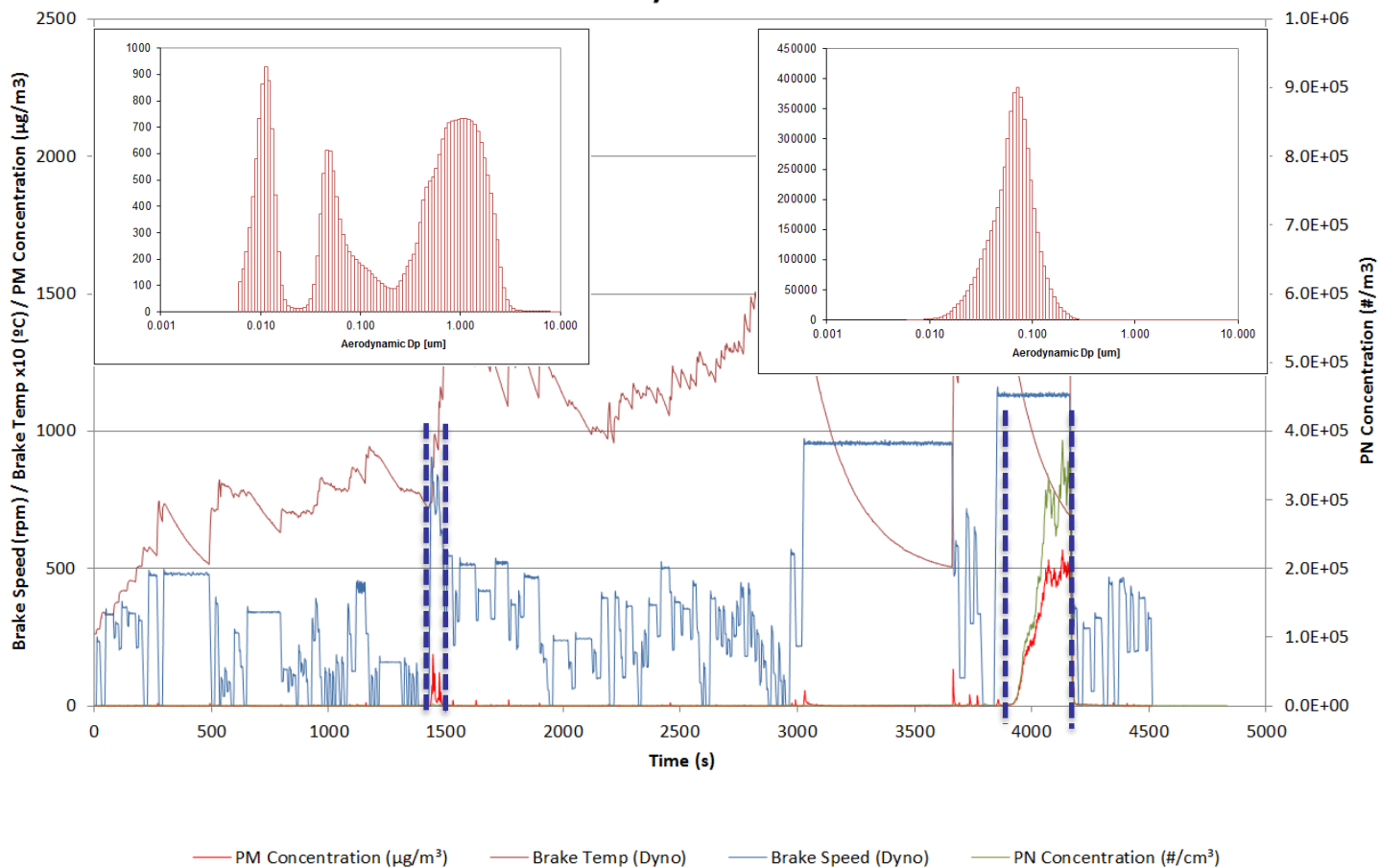
Main Data Analysis (in progress)

⊕ HRELPI+ and eFilter data (1100 m³/h)

⊕ Phase 10 (WLTC Cycle)

There is an impact in the size distribution depending on the Brake conditions (speed, temperature, etc.)

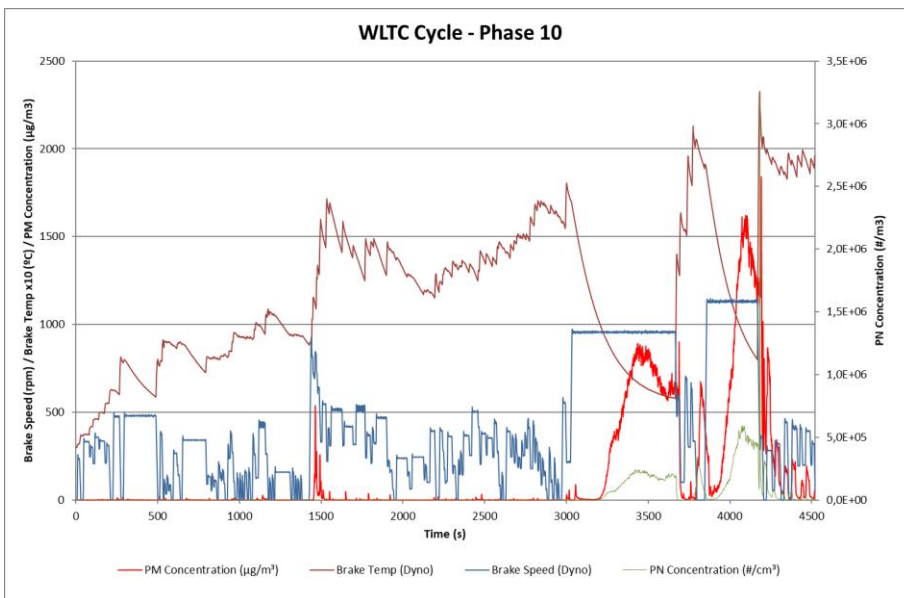
WLTC Cycle - Phase 10



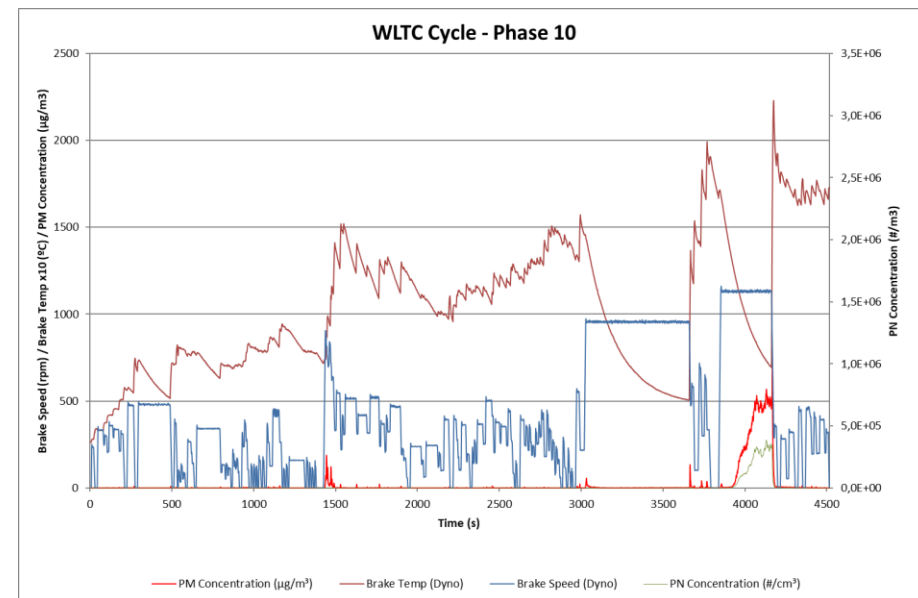
Main Data Analysis (in progress)

⊕ Interesting events founds (pending to analysis in detail)

- Air Flow influence
- Brake-off particles emissions



Air flowrate 600 m³/h



Air flowrate 1100 m³/h

- There is a clear **influence** both on the **PN and PM measurements** depending on the **air flow**
- **Brake-off events** has been detected and their understanding is on-going

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Conclusions & Open points to discuss

- ⊕ **Brake temperatures are moderately affected by the flowrate range of 600 - 1100 m³/h** → within 20°C (phase 10); the other phases maintain the delta from the start one or equalize towards the end of the phase.
- ⊕ **Novel WLTP Cycle PN emissions levels are 2 to 3 times higher at the 600 m³/h, on average.**
- ⊕ **There is an impact in the PN size distribution depending on the Brake conditions** (speed, temperature, etc.).
- ⊕ **PEGASOR device is more sensitive rather than the PEMS PN23 nm one.**
- ⊕ **Brake-OFF emissions** are present after a certain accumulation of particles in the brake system. Brake-OFF also happens under steady state speed!
- ⊕ **Brake-OFF emissions** - when present – have a significant levels and they may depend on the background of the brake system. Are 5,000 – 10,000 km required for a stabilized brake-off level?
- ⊕ **The PM and PN emissions are detected during 600 m³/h were at 1100 m³/h none** → sensitivity issue or particle coagulations / Nucleation / Wall losses?

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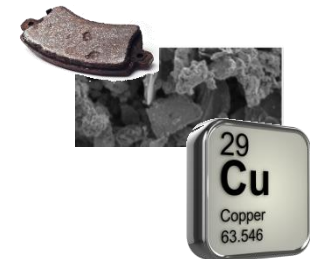
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⊕ Upcoming activities:

- Full test analysis completion
- Involvement in the PMP Working Group:
 - Future Task Force involvement
 - Test procedure final definition validation
 - Round robin activity within PMP selected members
- Brake Dyno bench and facilities:
 - Reinforcement of IDIADA's facilities for brake emissions collection
 - Data Acquisition Systems used according to PMP final definitions
 - Test programs designed to:
 - Fulfill PMP standardized procedures
 - Additional investigation studies and development projects





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