CHALLENGES IN THE DEVELOPMENT OF A COMMONLY ACCEPTED METHOD FOR MEASURING BRAKE DUST:

A HORIBA PERSPECTIVE…

30.10.2019; Joel Danzer, Dmytro Lugovyy, Yoshinori Otsuki

HORIBA

The „holy trinity“ of Brake Dust

Brake

Brake Dust

Emissions

Software

STARS Brake

Status of the PMP methodology

Valuable input, questions and remarks from our customers provide a good measure regarding the open issues

- HORIBA´s Brake Test Center in Flörsheim has been established in 2016 both for contract testing with customers and also for internal research
- HORIBA follows all recommendations given by the PMP-working group! Results have been presented!
- This presentation summarizes some of the „lessons-learned“ as well as an excerpt regarding the open issues, which needs to be addressed for a commonly accepted method for measuring Brake Dust!

Excerpt of the open issues (open for discussion within PMP TF1 + TF2):

- Bedding procedure
- Particle background concentration
- Brake enclosure requirements
- Cooling air requirements
- Residence time
- PM requirements
- PN requirements
- …
- Reporting/ data handling

How to read this presentation

general

- General information

blue

agreed

- Existent recommendations/ decisions from the PMP IWG

light red

tbd

- Open issues/ missing gaps in defining a commonly accepted methodology for measuring Brake Dust

green

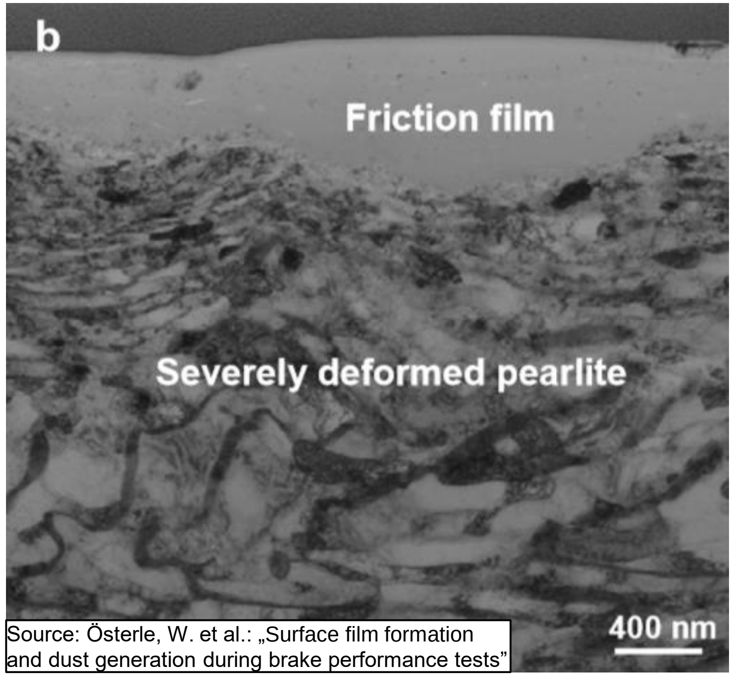
Bedding procedure (part I)

general

- Bedding: Mechanical conditioning of the Brake surface in order to produce a consistent transfer layer and get a stable friction coefficient µ
- Removal of potential anti-corrosive coatings
- Ensure reproducible particle emissions

agreed

- Perform a bedding procedure in accordance of the subsequent test cycle to avoid the „memory effect" (or any other falsifying effects…)
- Perform 4-5 repetitions of the WLTC-novel with data-logging on
  - 4 cycles last 18 hours + soak times (~4 hours in total) + purging between the cycles (~2 hours in total) → 24 hours of bedding!



Source: Österle, W. et al.: „Surface film formation and dust generation during brake performance tests"

tbd

- We should define more detailled criteria for the bedding procedure! See some of the open issues on the next slide

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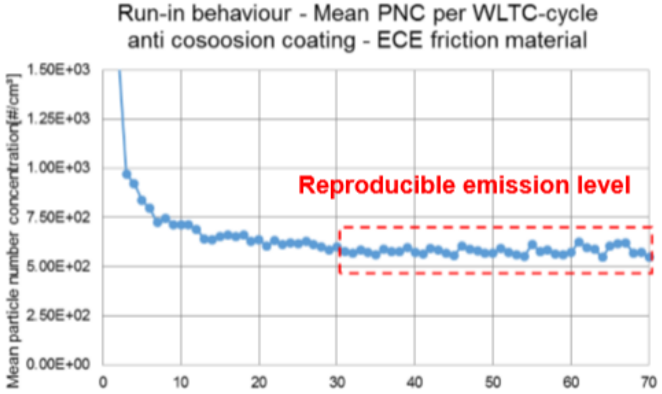
Bedding procedure (part II)

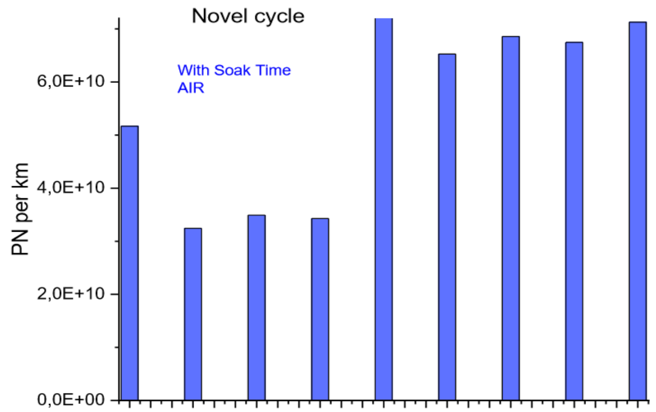
tbd

- Criteria when the bedding is finished? What metric should be used (PN, PM, µ)?
  - HORIBA suggests using integrated PN values for the bedding. However, subsequent cycles needs to be taken into account when defining proper criteria (see examples on the right side of this slide!)
- Do we need different bedding procedures or criteria for different brake materials (ECE/ NAO)?
- What recommendations are given for the purging between the cycles during the bedding procedure?
  - Can we combine this with requirements for the particle background concentration (procedure + limit tbd)
- What needs to be reported regarding the bedding procedure (if any)?
- Any chance to shorten the bedding procedure?



Source: TU Ilmenau + BMW (PMP47)

ECE; WLTC



NAO; WLTC-novel

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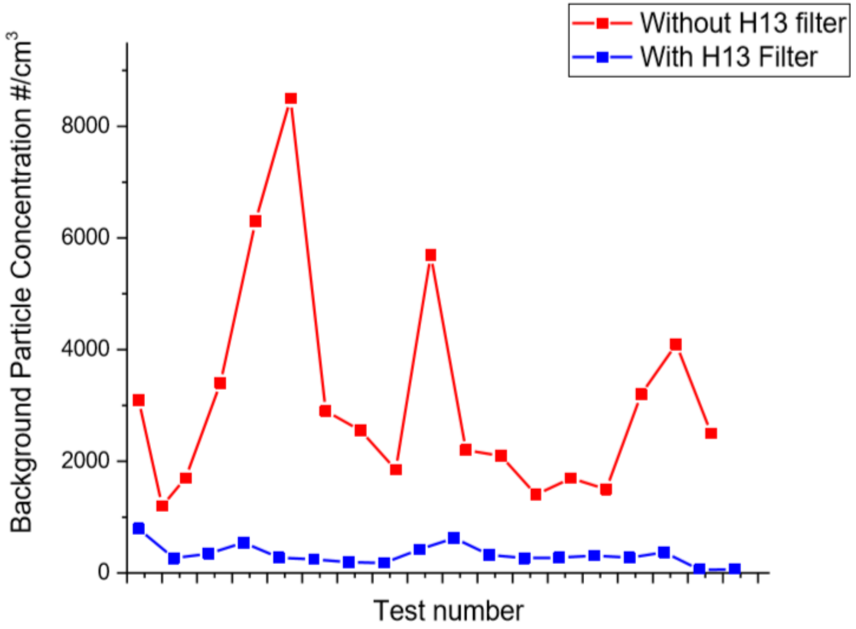
Particle background concentration

agreed

- Install a H13 filter in the cooling air duct in order to minimize the particle background concentration during the brake emission testing
- Correct the measured, integrated particle emissions over the test cycle by the particle background concentration

tbd

- The particle background concentration measurement needs to be described in detail (pre- and/ or post-test? Criteria for the permissible background concentration over a time x? Reporting? …)
  - Almost every emission legislation got something like a „zero-check“. For Brake Dust we could follow a similar approach (although we will not reach a zero-level! The limit could be in the range of <300#/cm³ over e.g. 20 minutes…)
- How do we handle PM? A PM background concentration can not be measured gravimetrically due to low loadings…
- What about the volatile PN background concentration?



Brake enclosure/ cooling air (part I)

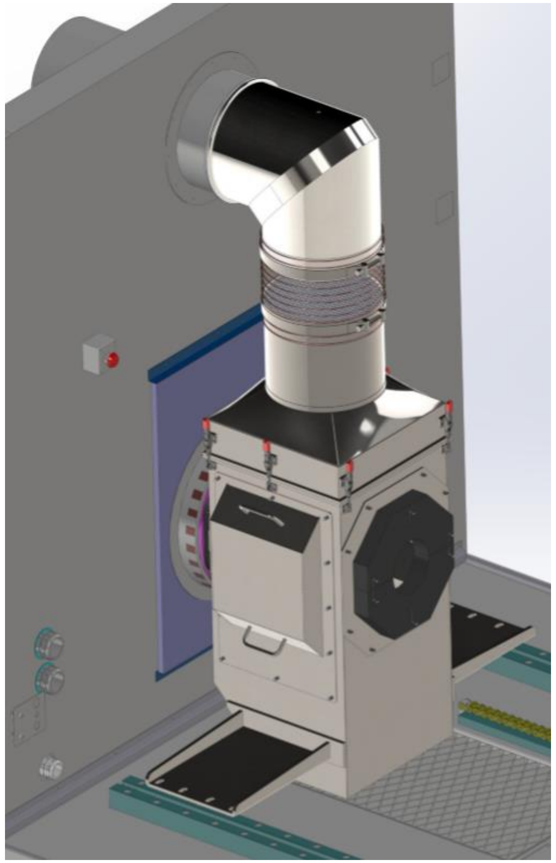
general

- A lot of different designs and operation conditions have been presented by the individual partners within the PMP IWG
- It is targeted <u>not</u> to exclude certain designs in this early stage of the development of a commonly accepted methodology for measuring Brake Dust.
- Physics require to look into the brake enclosure and the cooling air in dependence of each other! A cooling air flow rate or velocity can not be defined without a requirement for the dimensions of the cooling air duct (or the brake enclosure)

$$Q = v_A \cdot A$$

agreed

- The cooling air flow should be constant during the entire test
- Use a brake enclosure design and materials to minimize particle losses
- Use a brake enclosure design to minimize flow disturbances



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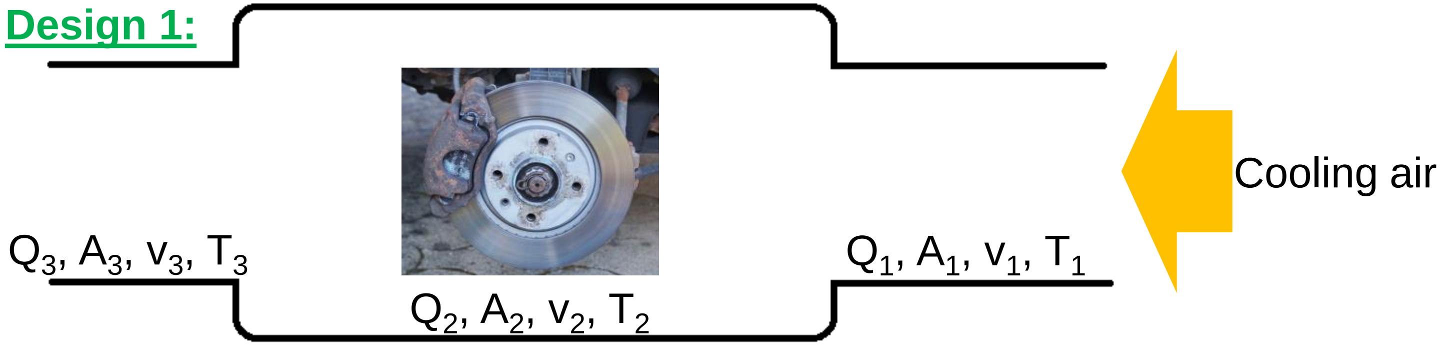
Q= Volume flow rate
v= Flow rate velocity
A= Cross-section area

Brake enclosure/ cooling air (part II)

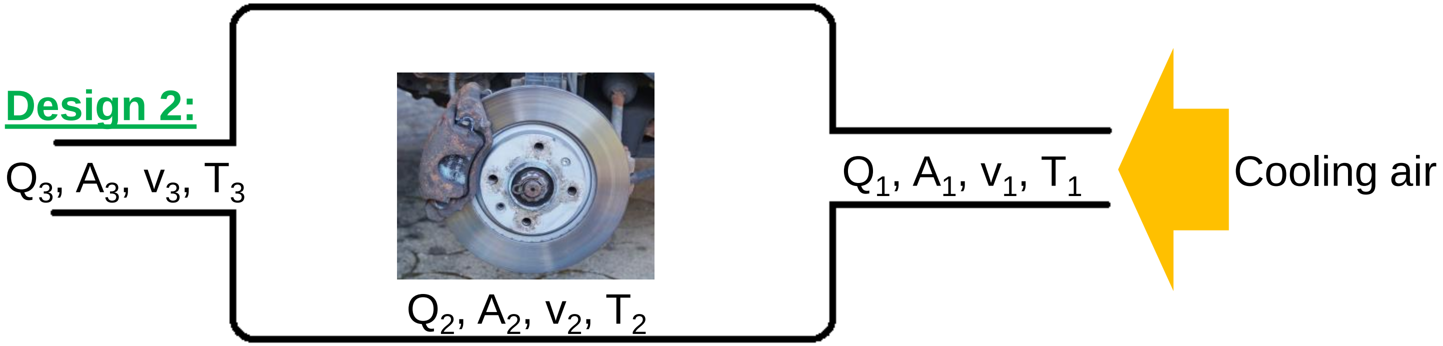
tbd

- In general: It should be targeted to describe the terms „minimize particle losses“ and „minimize flow disturbances“ a little bit more in detail!
- HORIBA highly recommends to define at least some basic design guidelines and technical requirements for the brake enclosure/ cooling air
- All setups shown by the PMP IWG partners are following one of the two designs shown on the right side of this slide

Design 1:



Design 2:



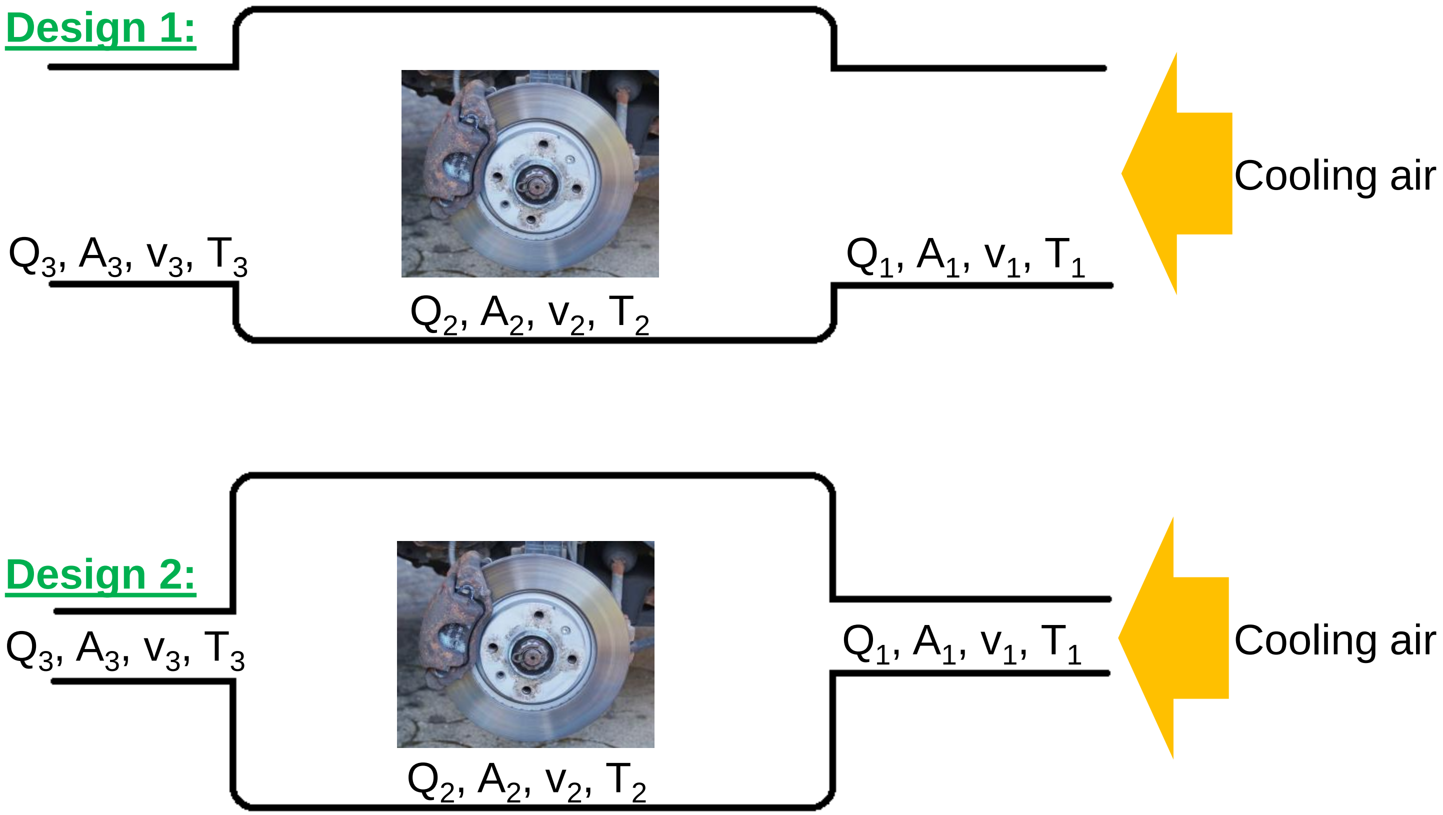
Q= Volume flow rate
A= Cross-section area
v= Flow rate velocity
T= Temperature

Brake enclosure/ cooling air (part III)

tbd

General comments:

- Design 1:
  - A_1 ensures that the entire brake cross-section area is hit by the cooling air flow. Optimized particle transport
  - A_2 being similar to A_1 minimizes uncontrolled conditions in the enclosure
- Design 2:
  - Technical solutions needed for the entry of the enclosure to minimize void areas
  - Particle losses/ good mixing expected at the entry of the exhaust duct
  - Low air exchange rate in the brake enclosure leading to higher brake temperatures and higher residence times increasing the particle losses



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Q= Volume flow rate
A= Cross-section area
v= Flow rate velocity
T= Temperature

Brake enclosure/ cooling air (part IV)

Setting cooling air requirements based on the brake temperature

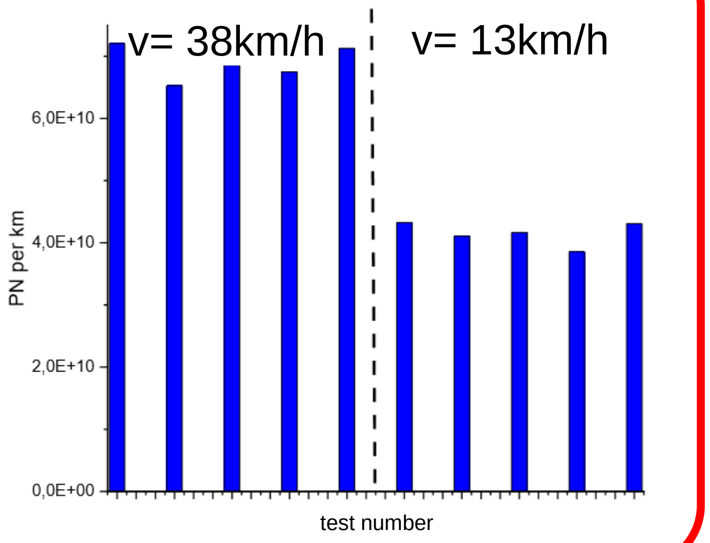
WLTC-novel Temperature measurement

WLTC-novel phases										
1	2	3	4	5	6	7	8	9	10	
44,23	50,8	38,4	45,8	41,8	12,7	24,3	38,9	24,2	44,7	Reference: Ford on-road measurement (average brake temperature)
55	64,8	53,2	60,3	57,3	21,3	30,9	49,4	24,3	60,7	Reference laboratory: Dyno measurement w/o enclosure (average brake temperature)
75,6	93,6	69,8	74,4	76,2	33,4	39,7	64,4	35,2	86	Reference laboratory: Dyno measurement with enclosure (average brake temperature)
55,9	67,7	57,1	64,2	57,9	26,7	36,8	51	29,5	61,4	HORIBA approach with enclosure (average brake temperature)

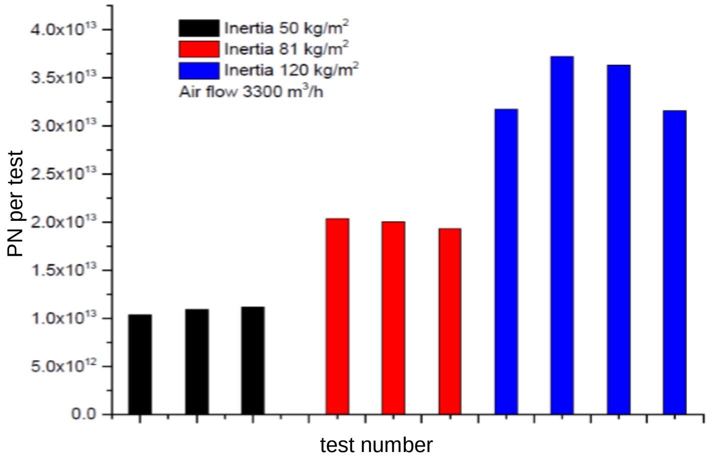
tbd

- The brake temperature regime is not the only influencing factor on the emissions!
- Without any design guidelines, setting the cooling air requirements based on the brake temperature might lead to highly incomparable results regarding the emissions!

Influence of cooling air velocity on PN



Influence of inertia on PN



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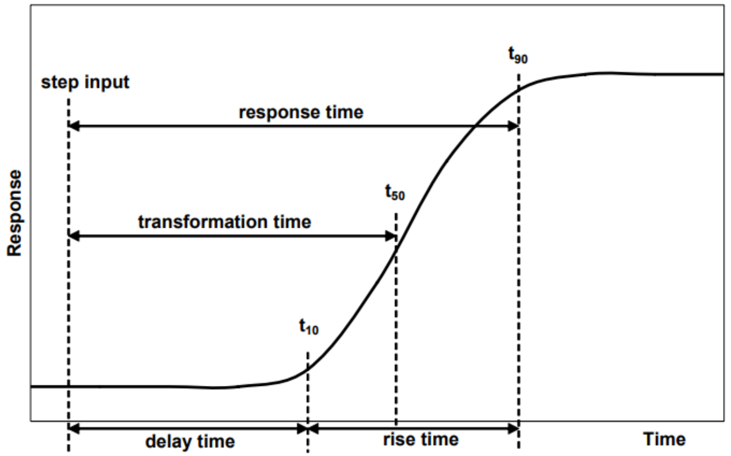
Residence time

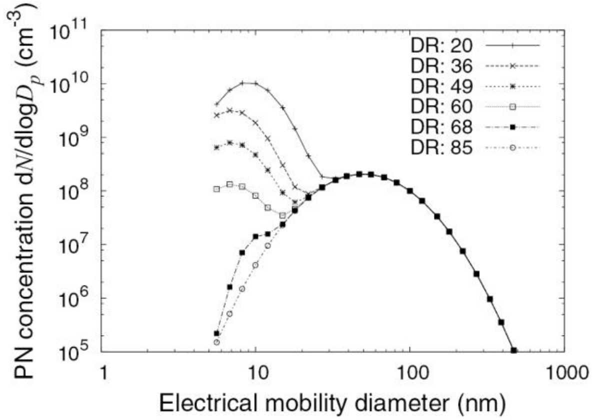
general

- A step input (e.g. a braking event) is not measured immediately! Emitted particles are transported from the point of emission through the entire system setup (brake dyno + measurement instrument) before they are actually detected
- In the exhaust legislations, the transformation time t_{50} is usually used for the time alignment between the vehicle and the instrument detector

tbd

- No criteria are defined yet for the residence time!
- It needs to be considered that different flow rates/ flow velocities in different laboratories lead to significant differences in the residence time within the exhaust duct
- Considering that the Brake Dust Application deals with (small, instable, sometimes magnetic) nanoparticles, the time spent in uncontrolled conditions should be as low as possible!





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HORIBA DLS-ONE:

Particulate matter (PM)

general

- “Particulate matter (PM)" means any material collected on a specified filter medium after diluting it with a clean filtered diluent
- Based on measurement results presented by the PMP IWG partners such as HORIBA, AVL, JARI and others, approx. 30-90% of the total PM is $PM_{2,5}$

agreed

- PM should be measured gravimetrically ($PM_{2,5}$ and PM_{10} are within the scope of this project)
- Indirect measurements, conversions and corrections should be avoided
- Isokinetic sampling should be realized (Any criteria regarding U_0/U?)!

tbd

- A stable flow through the filter medium with a defined filter face velocity should be targeted
- Low filter loadings needs to be considered in a quite moderate cycle like the „WLTC-novel“ when introducing multi-cascade impactors (consider aluminium-foil handling/ baking/ weighting as well as precision!)
- Detailled specifications for the cyclonic seperators, the filter media, the weighting method etc. are required!

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HORIBA MEXA-2110SPCS:

Particle number (PN)

general

- There is a strong focus on sub 23nm PN for engine exhaust emissions! The EU-Commission funded 3 projects under the umbrella of Horizon 2020. Several TF2 members such as HORIBA, AVL and TSI participate in those projects
- The political roadmap clearly points towards a 10nm threshold

agreed

- PN should be measured by means of a full-flow CPC
- Indirect measurements, conversions and corrections should be avoided

tbd

- What needs to be measured? Solid PN or total PN? Please consider measurement uncertainty as well as the calibration!
- What about volatile background concentration?
- The calibration procedure has not been discussed yet

PEMs 4Nano

DOWN TO 10

SUREAL-23

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HORIBA PERSPECTIVE

Using best-engineering practice until the finalization of a “commonly accepted method for measuring brake dust”

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HORIBA solution at a glance

1. HORIBA Brake Dyno Modifications

- Minimize particle losses
- Improve measurement repeatability

2. HORIBA Measurement systems

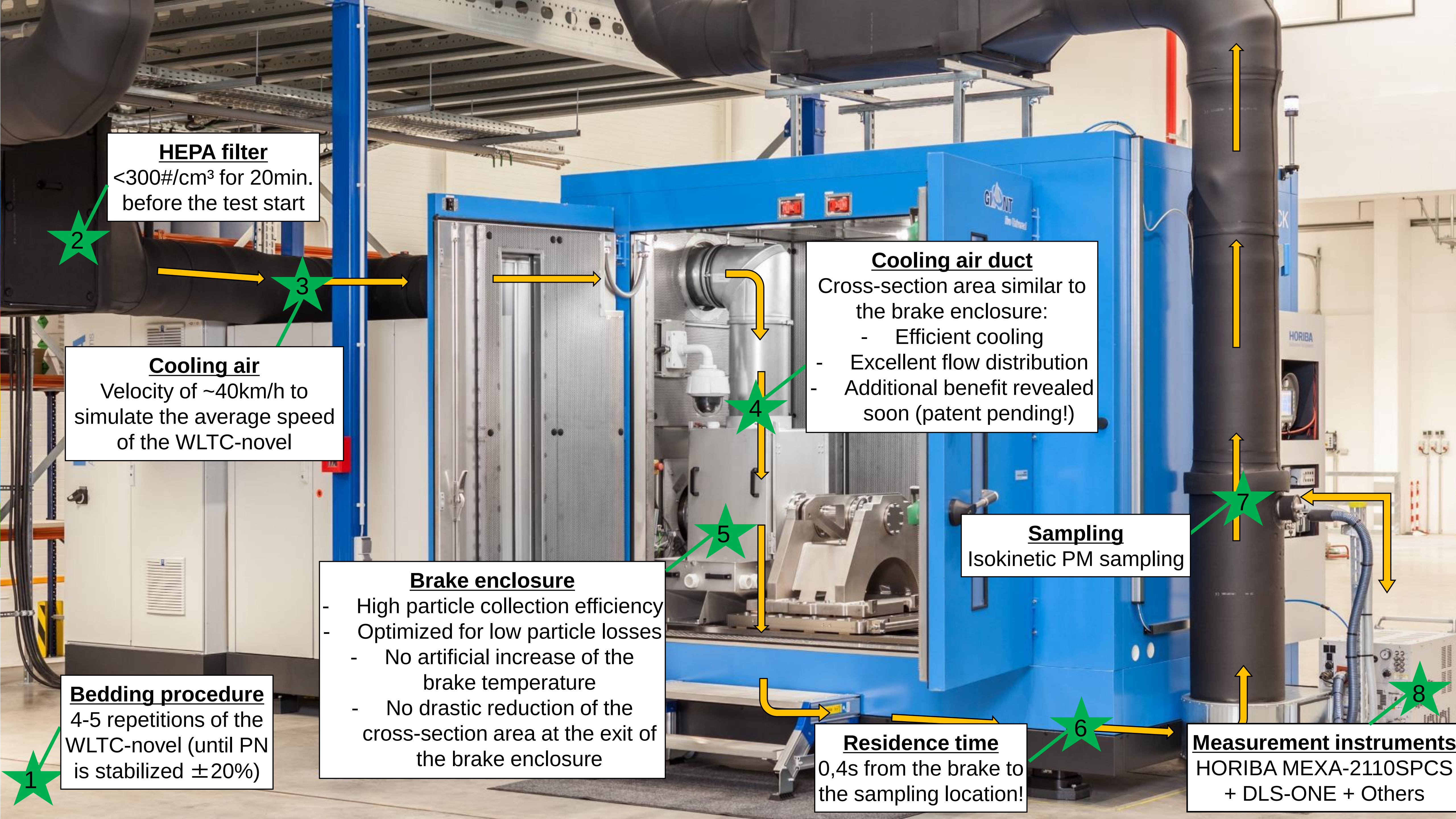
- 2110-SPCS for PN measurements
- DLS-ONE for PM measurements

3. HORIBA global service force

- HORIBA has a globally positioned service force of experienced engineers

4. HORIBA know-how/ expertise

- Our customers can gain experience regarding our concept in our Brake Test Center in Flörsheim/ Germany



HEPA filter
<300#/cm³ for 20min. before the test start
Cooling air
Velocity of ~40km/h to simulate the average speed of the WLTC-novel
Cooling air duct
Cross-section area similar to the brake enclosure:
- Efficient cooling
- Excellent flow distribution
- Additional benefit revealed soon (patent pending!)
Sampling
Isokinetic PM sampling
Brake enclosure
- High particle collection efficiency
- Optimized for low particle losses
- No artificial increase of the brake temperature
- No drastic reduction of the cross-section area at the exit of the brake enclosure
Bedding procedure
4-5 repetitions of the WLTC-novel (until PN is stabilized ±20%)
Residence time
0,4s from the brake to the sampling location!
Measurement instruments
HORIBA MEXA-2110SPCS + DLS-ONE + Others
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2
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Contact

HORIBA Europe GmbH

Joel Danzer
Hans-Mess-Straße 6
61440 Oberursel (Germany)

Phone: +49 6172-1396-325
Mobile: +49 1520-1053928

E-Mail: joel.danzer@horiba.com

Web: http://www.horiba.com

Thank you

Cảm ơn

감사합니다

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்றி

ขอบคุณครับ

Gracias

Obrigado

Σας ευχαριστούμε

Děkuji

Teşekkürler

شكرا

Tack ska ni ha

Danke

Большое спасибо