measuring and sampling for brake emissions using standardized inertia dynamometer methods

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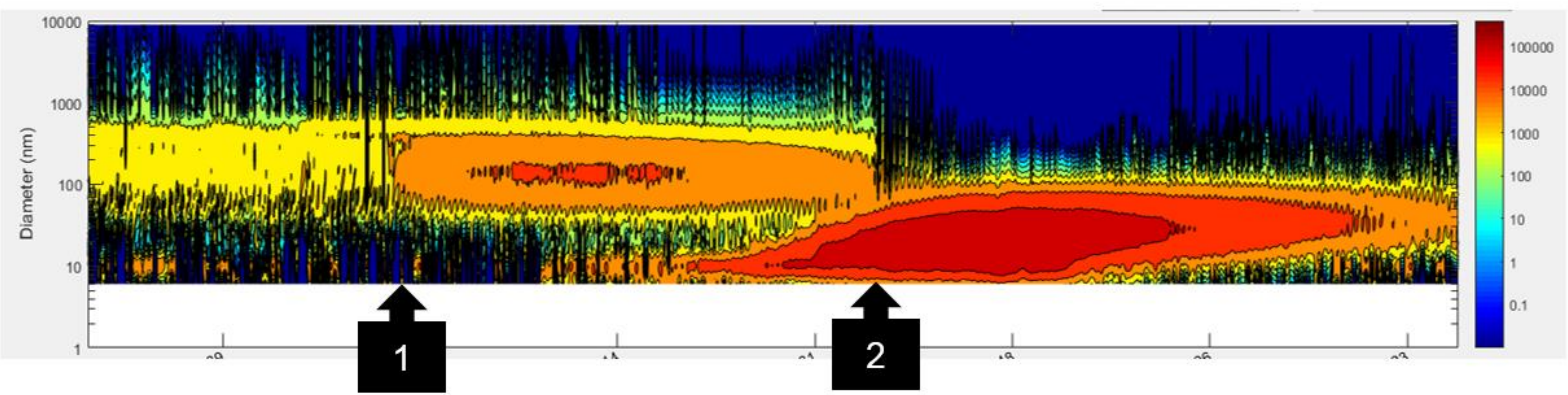
challenge



brake application

brake release


complexity, harmonization, contribution

topics

LINK's approach

system layouts

losses and isokinetics

minimum specifications

LINK's approach

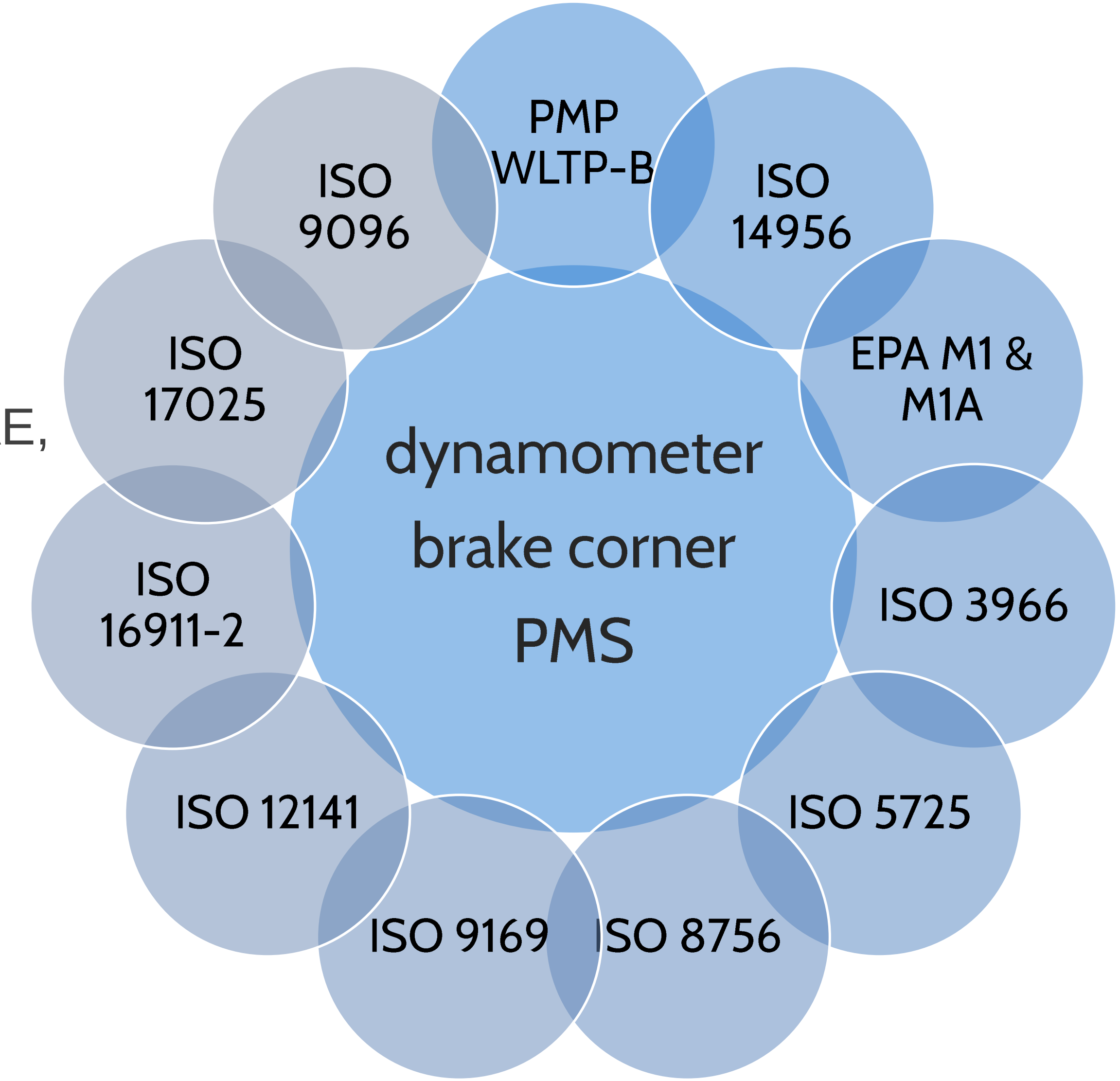
update/upgrade to current dyno designs

ruggedness (multisystem, isokinetics, direct data)

repeatability (fixture, environmental, duct finish)

testing environment

- ☑ open data
- ☑ sync ISO, JSAE, SAE, and PMP
- ☑ brake, dyno, PMS agnostic



examples only

- ☒ toxicology, health aspects, or chemistry
- ☒ commercial vehicles
- ☒ regulation / rulemaking

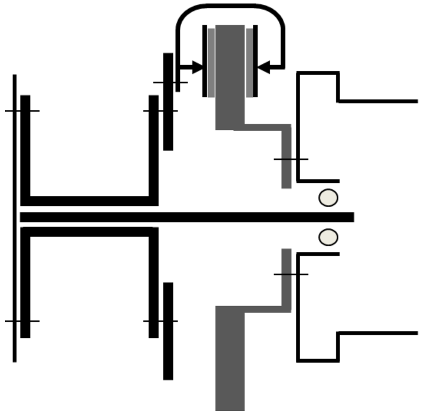
ISO 9096

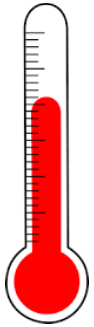
Table 3 — Summary of requirements — Apparatus and sampling conditions

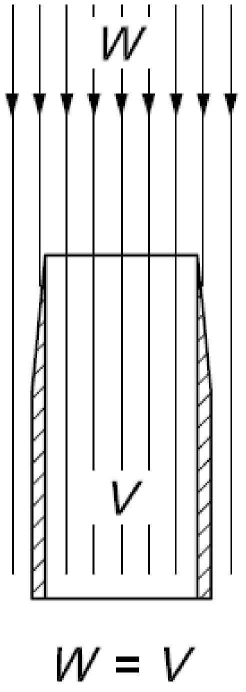
Equipment for dust collection	**Value**
Nozzle internal diameter, *d*	> 4 mm
Nozzle area: measurement uncertainty	±10 %
Nozzle: length with constant internal diameter	> 10 mm
Nozzle: variation in diameter angle	< 30°
Elbow: radius of the bend	> 1,5*d*
Nozzle straight length before the first bend	> 30 mm
Nozzle tip: distance to obstacles	> 50 mm
Filter efficiency (test aerosol 0,3 µm)	> 99,5 %
Filter material (absorption of components)	No reaction and no absorption
Condenser, drying tower: residual gas moisture	< 10 g/m^3
Gas meter volume measurement uncertainty	±2 %
Absolute pressure measurement uncertainty	±1 %
Absolute temperature measurement uncertainty	±1 %
Alignment of the nozzle	±10 %
Isokinetic criteria (average measurement uncertainty)	$^{+15}_{-5}$ %
Leak test	< 2 %
Balance resolution (mg)	0,01 mg to 0,1 mg
Weighing uncertainties	< 5 % of the LV[a] set for the process (see 7.4.4)
Thermal stability duration of probe-housing filter heating	> 8 h
Overall blank value	< 10 % of the LV[a] set for the process or 2 mg/m^3, whichever is smaller
Sampling time measurement uncertainty	±5 s
Linear measurement uncertainty (duct diameter)	±1 %
(nozzle diameter)	±0,2 mm or ±5 %, whichever is greater
Sampling location	
Flow angle	< 15°
Negative flow	None
Pressure difference (Pitot tube)	> 5 Pa
Ratio of max. gas velocity to min. gas velocity	3:1
Straight length before the sampling plane	> 5 hydraulic diameters (recommended)
Straight length after the sampling plane	> 2 hydraulic diameters (recommended)
Straight length before emission point	> 5 hydraulic diameters (recommended)
Number of sampling points	See Tables 1 and 2
Equipment for flue gas characteristics	
Absolute temperature	±1 %
Flue gas density	±0,05 kg/m^3

[a] LV = limit value.

air handling







η gravitational setting

η diffusional deposition

η turbulent inertial deposition

η constrictions

etc, etc,

boundary conditions

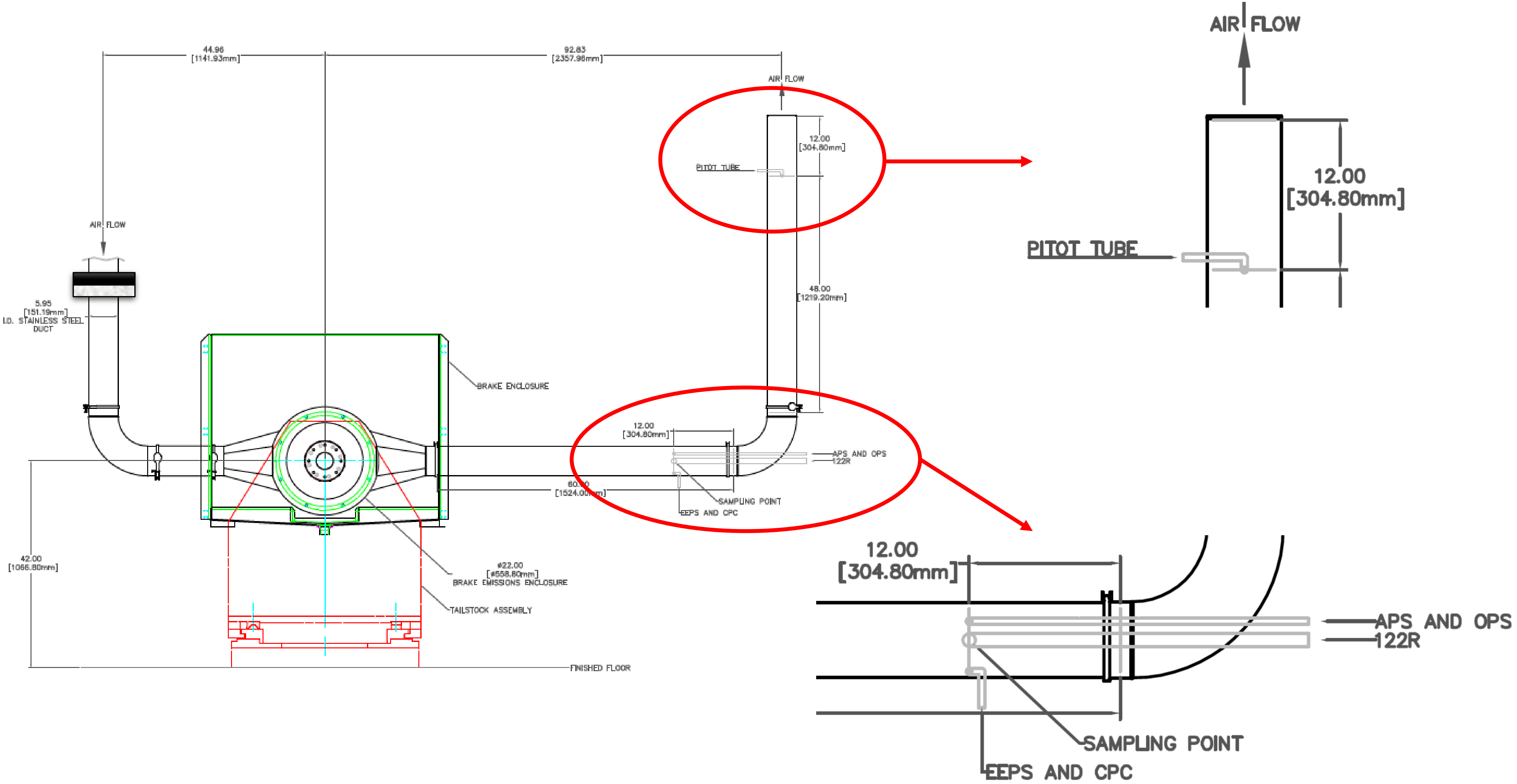
R"5 (250-2500) m³/h – volumetric airflow

R"5 (100-250) mm – duct diameter

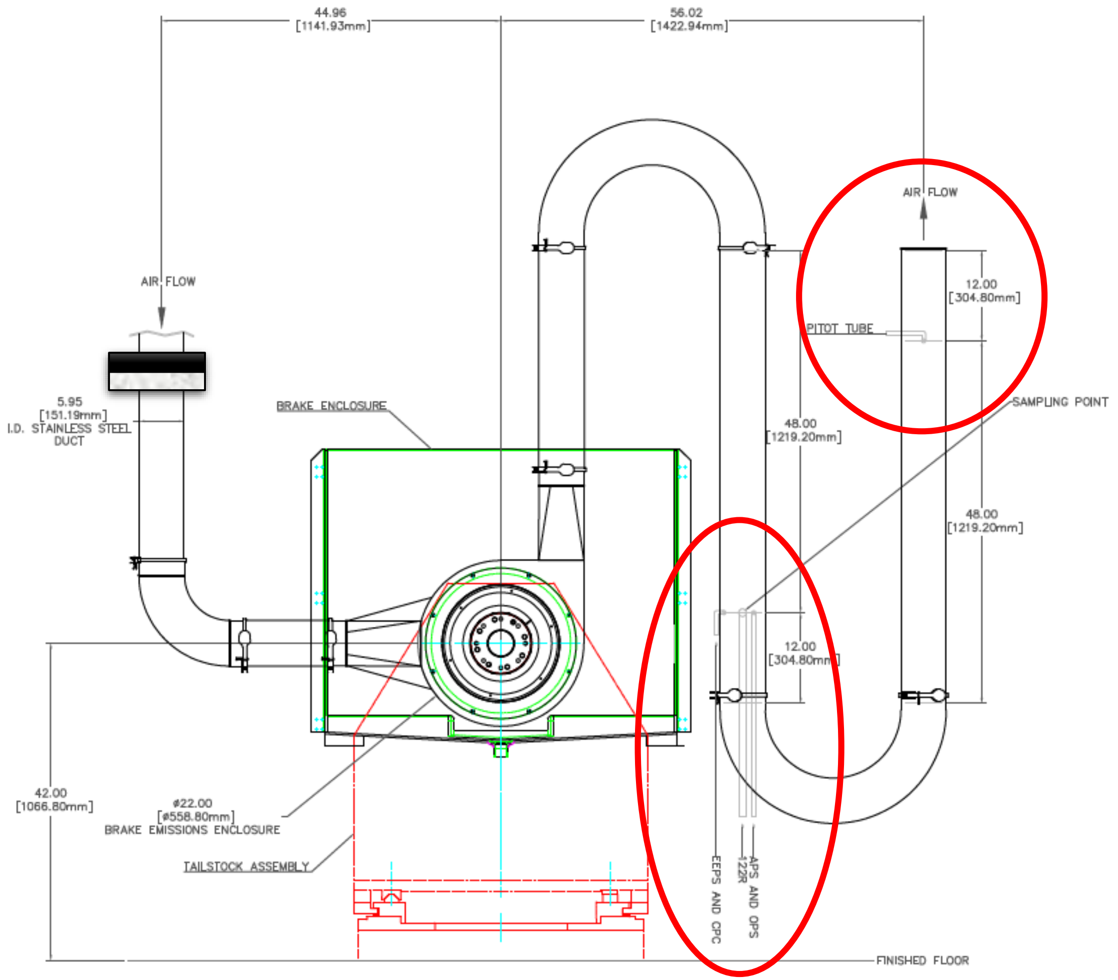
R"5 (4-40) l/min – sampling airflow

air speed entering the brake enclosure

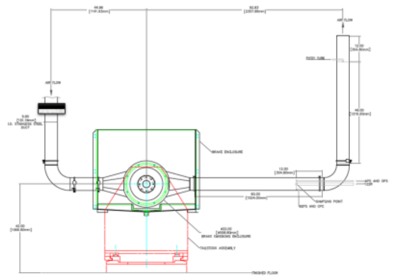
horizontal duct layout

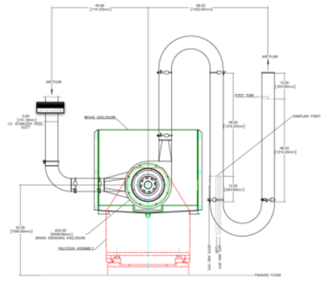


vertical duct layout



side-by-side





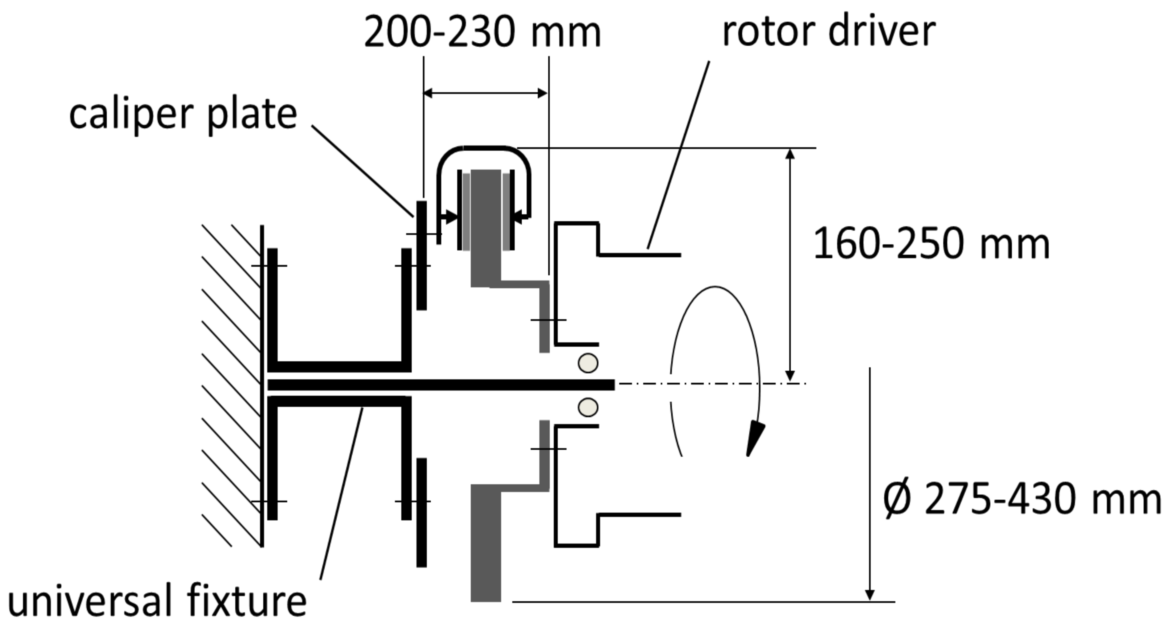
(+)

dyno upgrade, not a new one	dyno upgrade, not a new one
allows isokinetics	allows isokinetics (vertical sampling)
shorter particle transport to sampling	smaller floor space (+250 mm)
simpler design & fabrication	

(-)

wider floor space (+1300 mm)	longer particle transport to sampling
horizontal sampling (isokinetics)	fabrication and electropolish

fixtures



minimal interruption to airflow
allows smaller enclosure size
provides predictable interface with enclosure seals

fixtures

do

minimal interruption to airflow

allows smaller enclosure size

provides predictable interface with enclosure seals

don't

unpredictable turbulence around the brake

limits orientation of the brake inside the enclosure

convoluted method to ensure proper sealing (contamination or losses)

Particle Measurement System – PMS

5.6-560 nm

1-to-10,000 #/cm³

0.01-20 µm

0.37-20 µm

0.37-10 µm

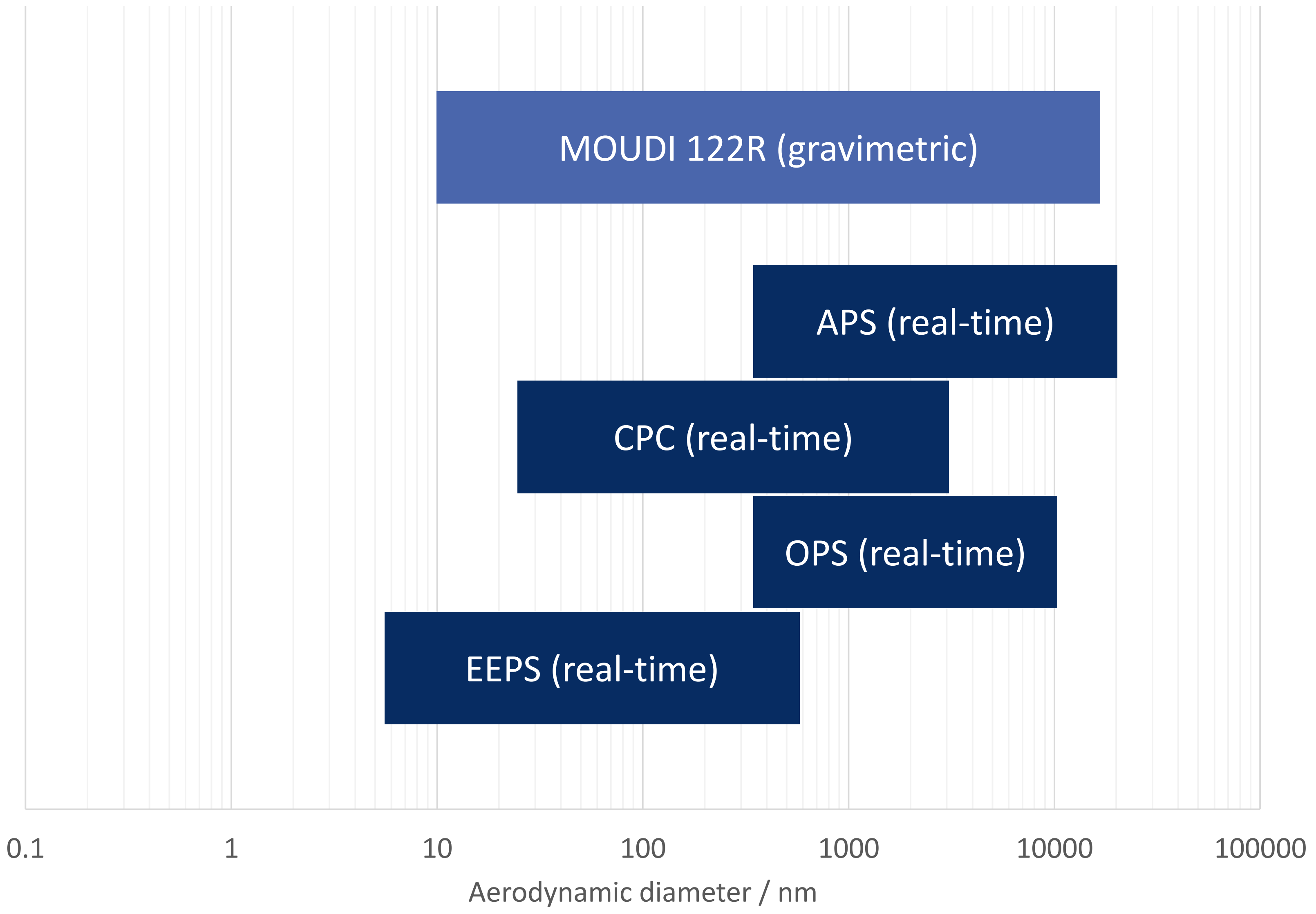
EEPS & EECPC (11 l/min)

Moudi 122R
(30 l/min)

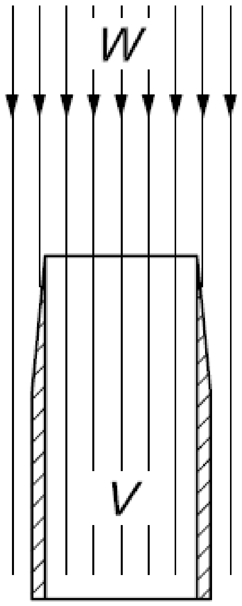
APS & OPS
(6 l/min)

Isokinetic sampling

multisystem



isokinetic sampling (aspiration) for micron-range particles

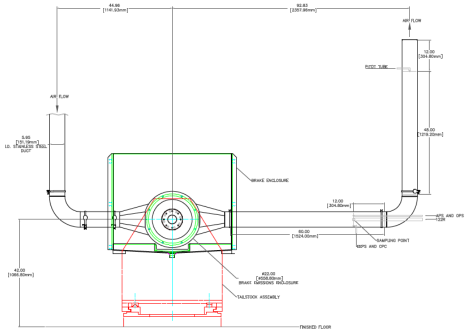


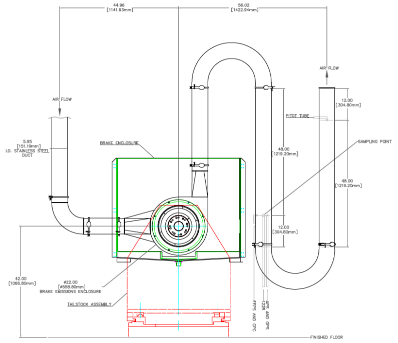
$$n_{asp} = 1 + \left[\frac{U_0}{U} - 1\right]\left[1 - \frac{1}{1 + 3.77 \cdot Stk^{0.883}}\right]$$

Rader and Marple – with correction for nozzle tip
0.005 < Stk < 10 and 0.2 < Uo/U < 5

duct transport efficiency

P. Kulkarni et al
W. Hinds
T. Mercer





constriction

$$\eta_{cont,inert} = 1 - \frac{1}{1 + \left\{ \frac{2 \cdot Stk \cdot \left[1 - \left(\frac{d_o}{d_i} \right)^2 \right]}{3.14 \cdot \exp(-0.0185 \cdot \theta_{const})} \right\}^{-1.24}}$$

diffusion

$$n_{asp,diff} = exp\left[-\frac{\pi \cdot D \cdot L}{Q} \cdot 0.0118 \cdot Re^{7/8} \left(\frac{\eta}{\rho_f \cdot D} \right)^{1/3} \right]$$

turbophoresis

$$\eta_{tube,turb\ inert} = exp\left[-\frac{\pi \cdot L \cdot V_t}{Q} \right]$$

gravitational

$$\eta_{tube,grav} = exp\left[-\frac{d \cdot L \cdot V_{ts} \cdot cos\theta}{Q} \right]$$

bend

$$\eta_{bend,\, inert} = exp[-2.823 \cdot Stk \cdot \theta_{bend}]$$

Possible arrangement of sub working groups:

- air handling and isokinetics
- particle measurement system(s)
- calibration, sign-off, and verification

topics

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