RDE for powered Two-Wheelers.

AiP

From Lab to Road: Future-Proof Emission Testing for Motorcycles

with AIP

Executive Summary

Motorcycle RDE – The Next Frontier

Future legislation may require motorcycles to align more closely with passenger car standards. This could include **new pollutants** such as PM for all engines, PN, and possibly NH_3, as well as the introduction of **Real Driving Emissions** (RDE) testing. These changes would represent a major shift from purely laboratory-based cycles to real-world compliance.

Why Adaptation Is Essential

Motorcycles pose **unique challenges** for RDE testing: limited space for instrumentation, diverse engine architectures, and highly pulsating exhaust flows. These factors demand specialized solutions that combine accuracy with minimal impact on vehicle dynamics.

Proven Technology, Tailored for Motorcycles

Our lightweight Portable Emission Measurement System (PEMS) has been **extensively validated** in the LDV sector **and adapted** for two-wheelers. It integrates advanced analyzers for gaseous pollutants (NDIR, CLD, PAS) as well as a PMP-compliant PN measurement system, ensuring full coverage of current and anticipated requirements.

Validated Accuracy Across Different Motorcycles

A key innovation is the Low-Flow Exhaust Flow Meter (LF-EFM), **optimized for pulsative low-flow applications**. In a published study, the EFM demonstrated strong correlation with reference systems (R^2 up to 0.99) across eight motorcycles from different performance classes and engine architectures, confirming its reliability for real-world testing.

From Setup to Compliance

The solution covers the entire workflow: setup and calibration, on-road measurement with real-time driver feedback, and post-processing using recognized methods such as Power Binning (CLEAR) and Moving Average Window (EMROAD). Compliance evaluation follows international LDV standards, with flexible export options for further analysis.

Future-Ready Emission Testing

With compact hardware, intuitive software, and regulation-ready methodologies, AIP enables OEMs and testing organizations to meet upcoming challenges confidently, delivering accurate, efficient, and **future-proof** RDE testing for motorcycles.

RDE: The next Step?

Motorcycle emission standards have evolved significantly from Euro 1 to Euro 5, introducing stricter limits and new pollutants. Since Euro 4, the most substantial changes have been OBD-driven, with advanced diagnostics shaping fuel control, catalyst monitoring, and evaporative emission systems. While the European Union has not yet proposed Euro 6 legislation for motorcycles, trends indicate that future requirements could align more closely with passenger car standards.

What might change?

New Pollutants

- Particulate Matter (PM)
- Particle Number (PN)
- Ammonia (NH_3)

Real Driving Emissions (RDE)

Laboratory cycles have clear limitations, especially for high-performance motorcycles. Future legislation may introduce RDE testing, requiring on-road measurements under diverse conditions to ensure compliance beyond the test bench.

These potential changes highlight the need for adapted methodologies and **lightweight**, **high-precision PEMS solutions**, enabling accurate measurements without compromising vehicle dynamics and preparing the industry for what may come next.

Motivation

RDE would have beneficial insights for the development process and further a beneficial impact for the environment

Challenges

Assessment of real drive emissions on motorcycles poses several challenges just as packaging, dynamics and exhaust flow assessment.

	EURO 1	EURO 2	EURO 3	EURO 4	EURO 5	EURO 5-2	EURO 6
Fuel System	Carburetor	Carburetor	Carburetor EFi	Electronic Port Fuel Injection	Electronic Port Fuel Injection	Electronic Port Fuel Injection	Electronic Port Fuel Injection
Catalyst	No	No	Oxidation-Catalyst	3 Way Catalyst	3 Way Catalyst	3 Way Catalyst	3 Way Catalyst + ?
Diagnostic	No	No	No	OBD I	OBD II	OBD IIb	OBD IIb
Emission Cycle	ECE R40 + EUDC	ECE R40 + EUDC	ECE R40 + EUDC	WMTC	WMTC	WMTC	Real Drive Emissions
Pollutants	CO/THC/NOx			+ NMHC			+PN/PM/NH_3

[1] Adjusted from Ricardo, 2023.

RDE Setup for Motorcycles

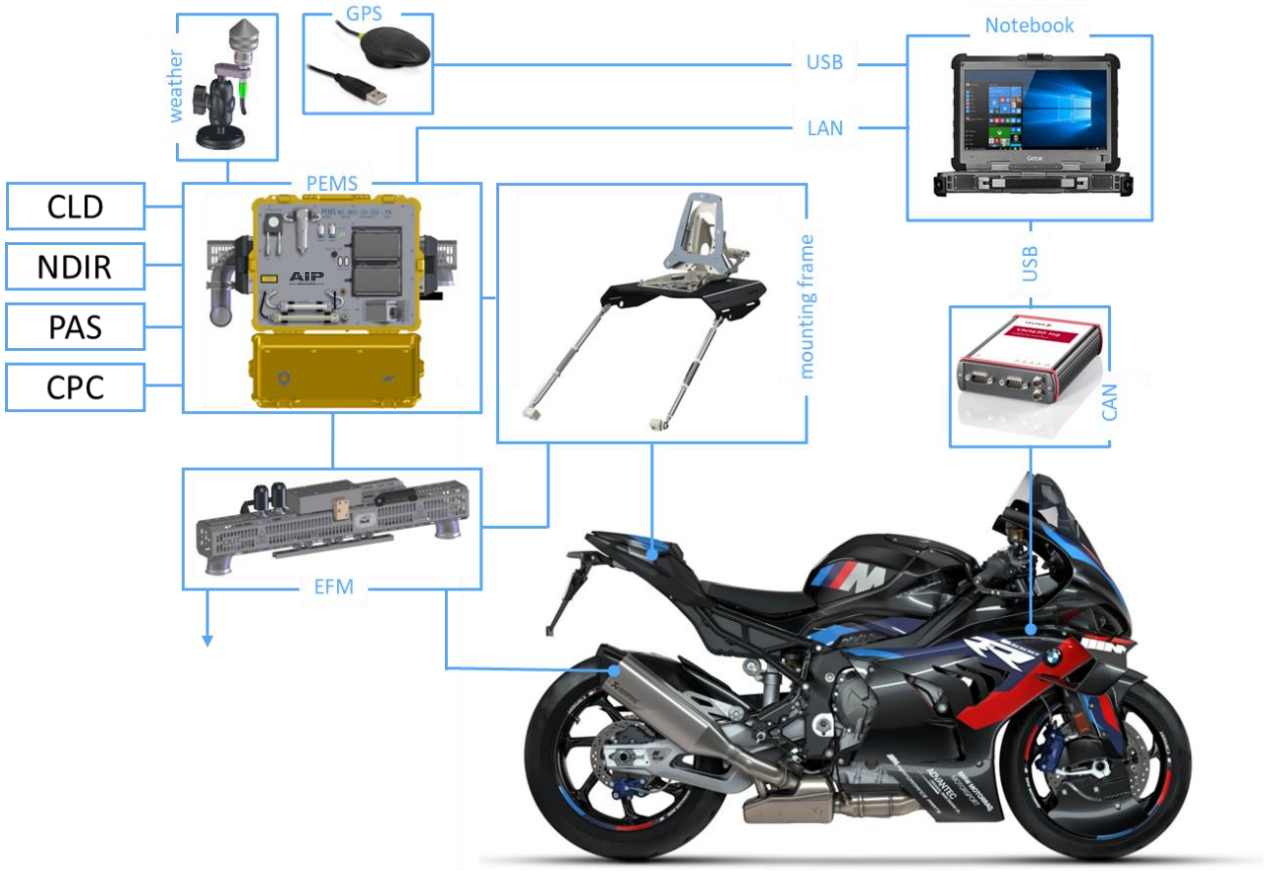
Carrying out Real Driving Emissions (RDE) measurements requires installing all measuring devices directly on the vehicle, a task that becomes particularly challenging for two-wheelers due to limited space and weight constraints. The illustration below shows a typical RDE setup for larger, high-performance motorcycles using a state-of-the-art automotive PEMS. Exhaust gas is extracted at full flow from the rear silencer and routed via flexible metal tubing to the Exhaust Flow Meter (EFM), where the exhaust mass flow is determined. A sample flow is then analyzed in the PEMS. Both systems, along with a notebook and additional equipment, are mounted on the rear of the motorcycle using a dedicated frame.

Equipment Requirements

According to LDV-RDE regulation, the following parameters must be recorded during an RDE test drive at a minimum data rate of 1 Hz:

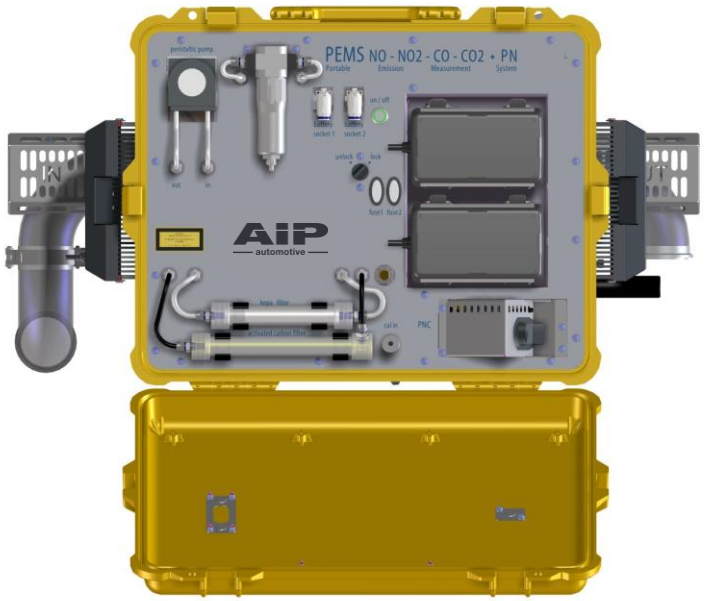
- Pollutants (PN, NOx, CO) and CO_2
- Exhaust gas mass flow
- GPS position and ambient conditions
- Selected OBD channels

The legislator demands that specifications for chassis dynamometer measurement technology, such as accuracy, noise, and repeatability, apply to LDV RDE equipment as far as possible. However, direct transfer of lab technology to the road is not always feasible, which is why alternative sensor principles are permitted for RDE applications



[2] Schurl, S., Keller, S., Lankau, M., Hafenmayer, C., Schmidt, S., & Kirchberger, R. (2025). RDE Methodology Development for Motorcycle Emissions Assessment. SAE International Journal of Advances and Current Practices in Mobility, 7(2024-32-0073), 1910-1922.

Instrumentation - PEMS



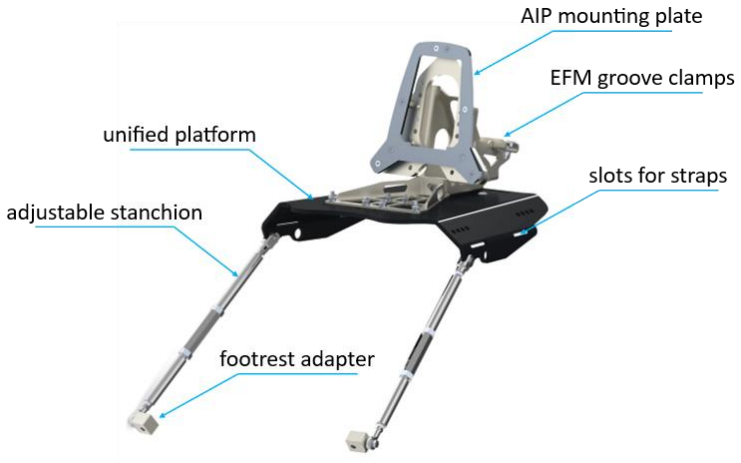
Portable Emission Measurement System

The PEMS used is designed for real-time determination of gaseous emission components including CO, CO_2, NOx ($NO+NO_2$), and PN from vehicles during actual driving conditions. This device is compliant with EU LDV-RDE legislation.

The instrument, shown, is housed within a robust, waterproof casing (IP57) featuring passive cooling and operates independently using Li-ion batteries. Careful attention was given to its lightweight design and the ability for easy mounting onto vehicles, which makes it best suitable for motorcycle RDE assessment. The case can be securely fixed onto the carrier using a click system.

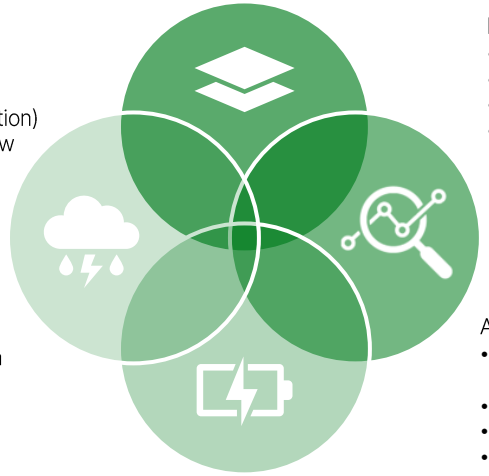
Technical Data:

Dimensions (DxWxH):	292×714×492 mm
Weight:	approx. 30 kg incl. 2 Li-Ion batteries
Ambient operational range:	0°C - +35°C | 0-100%, RH | 650-1200 mbar



Environmental conditions
- 0 ° C to 35 ° C
- Relative humidity up to 100%
- Altitude up to 2500 m (China Regulation)
- Protection against dust, water & snow Resistant to vibration, rapid pressure changes and sun radiation

Power Supply:
- Self-sufficient power supply over 2 h
- Efficient operation



Design:
- Compact and portable
- Low Weight
- Robustness in all applications
- Easy handling

Accuracy:
- in real time (Selective, highly sensitive, absolutely cross-sensitivity-free)
- Good correlation
- comparability of measurement data
- easy calibration

Instrumentation

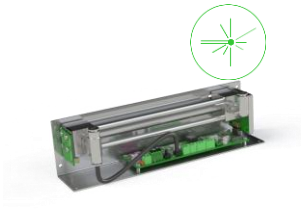
PEMS Gas Analyzers

Analyzers Inside the PEMS: How Gaseous Pollutants Are Measured

Portable Emission Measurement Systems (PEMS) integrate several analyzer technologies to ensure accurate detection of regulated gaseous pollutants under real-world conditions. For this purpose, a set of three independent analyzers including Non-Dispersive Infrared and Chemiluminescence Detector as well as a photoacoustic sensor is integrated in the compact case.

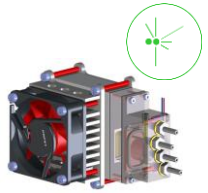
	Carbon Monoxyde $\lvert C{\equiv}O \rvert$	Carbon Dioxyde $O{=}C{=}O$	Nitrogen-oxyde $N{=}O$	Nitrogendioxyde $^{-}O{-}N^{+}{=}O$
Analyzer	NDIR	NDIR	CLD	PAS
Measurement range:	0 – 5 Vol.-%	0 – 20 Vol-%	0 – 2500 ppm	0 – 1000 ppm
Percision:	< 0,3 % of max	< 0,3 % of max	< 1 % of max	< 0,5 % of max
Noise:	< 0,3 % of max	< 0,2 % of max	< 0,4% of max	< 0,06 % of max
Zero-Drift (4h):	≤ 20 ppm	≤ 500 ppm	≤ 0,5 ppm	≤ 0,5 ppm
Span-Drift (4h):	≤ 2 % of reading or ≤ 20 ppm	≤ 2 % of reading or ≤ 500 ppm	≤ 2 % of reading or ≤ 3 ppm	≤ 2 % of reading or ≤ 3 ppm
Accuracy:	±2 % of reading or ±0,3 % of max (whichever is higher)			
Linearity:	gradient: 0,99 – 1,01 coerrelation r^2: ≥ 0,998 std. deviation SEE: ≤ 1% of max			

Together, these technologies enable precise measurement of CO, CO_2, NO, NO_2, and optionally N_2O, meeting stringent accuracy requirements for RDE testing and ensuring reliable data collection even under dynamic on-road conditions.



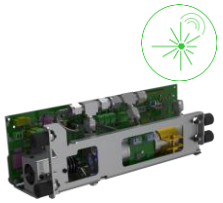
NDIR – CO and CO_2 Measurement

Non-Dispersive Infrared (NDIR) sensors determine gas concentrations by measuring the attenuation of infrared radiation at specific wavelengths. The calculation follows Lambert-Beer's law, and the measuring range is defined by the geometry of the cuvette, which typically varies in length from 1 to 250 mm and has a diameter of approximately 8 mm. An optional channel allows the same NDIR cell to measure nitrous oxide (N_2O).



Chemiluminescence Detector (CLD) – NO Measurement

The CLD uses the reaction of nitric oxide (NO) with ozone (O_3) to form excited NO_2 molecules. As these molecules return to their ground state, they emit photons, primarily in the red spectrum. The emitted light is captured by an optical system and a photomultiplier, and its intensity is directly proportional to the NO concentration.



Photoacoustic Sensor (PAS) – NO_2 Measurement

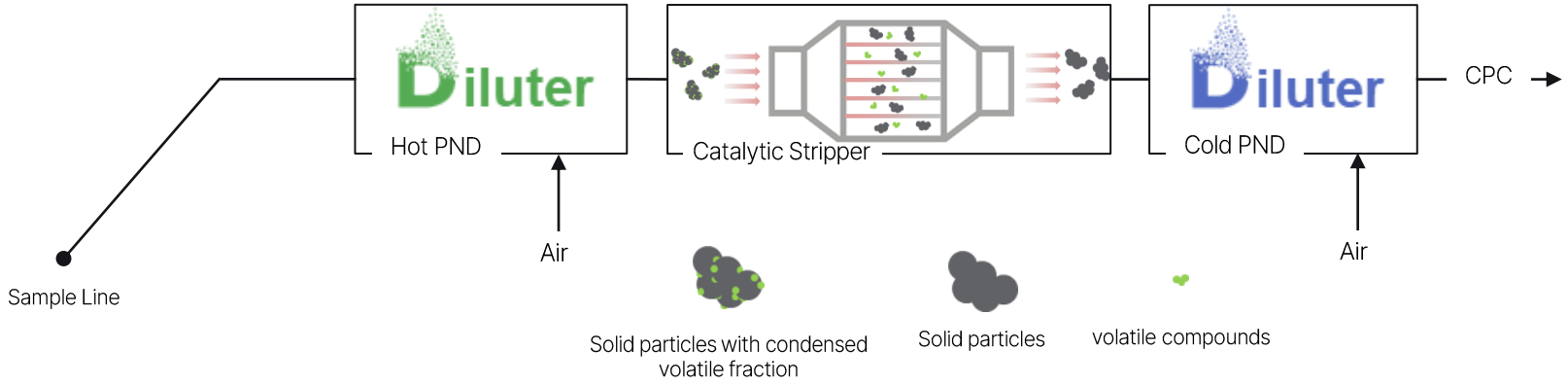
Photoacoustic spectroscopy is an optothermal method that converts absorbed modulated light into acoustic waves. When the sample is irradiated at a defined wavelength, part of the light energy is absorbed and transformed into pressure waves, which are detected by a microphone and analyzed to determine NO_2 concentration.

Instrumentation

PEMS Particle Analyzers

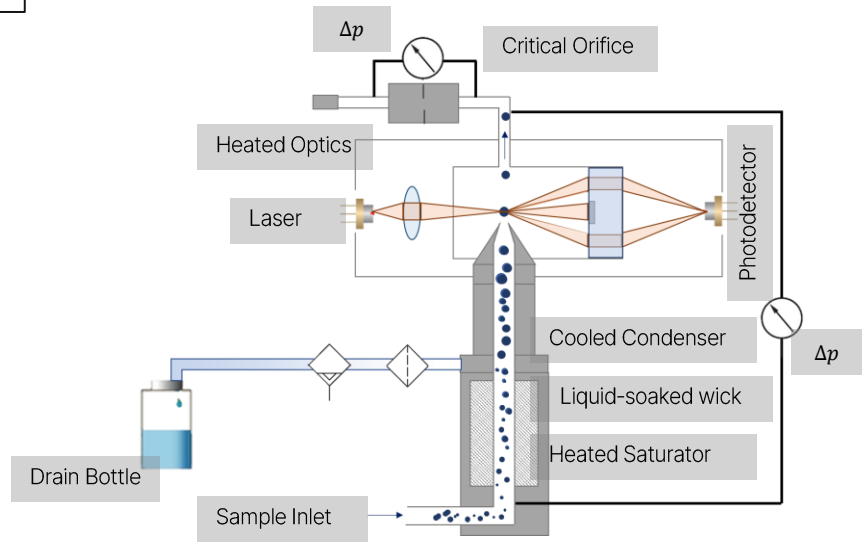
Analyzers Inside the PEMS: How Gaseous Pollutants Are Measured

The AIP PEMS-PN system is designed to determine the particle number concentration of **solid soot particles** in raw exhaust gas. It detects particles with an electrical mobility diameter from 23 nm up to approximately 2.5 µm, using a Condensation Particle Counter (CPC) for counting. The measurement system is based on the specifications of the **Particle Measurement Programme (PMP)** protocol, which forms the foundation of European regulations for particle number measurements in exhaust gases (UNECE R83 and RDE). Measurements can be evaluated according to RDE5 procedures, and on request, the counter can be calibrated for a 10 nm cut-off point to be ready for future regulations.
The PMP scheme consists of a hot diluter, a Volatile Particle Remover (VPR), a cold diluter, and finally the CPC. This sequence ensures that only solid particles are counted, excluding volatile components that could distort results.



Condensation Particle Counter (CPC)

CPCs are used to determine particle number concentration in engine exhaust. Nanoparticles, which are too small for direct optical detection, act as condensation **nuclei in** a **supersaturated alcohol vapor-air mixture**. This process forms micrometer-sized alcohol droplets around each particle. These droplets are then detected by **laser light scattering**, where each scattering impulse corresponds to one nanoparticle within the calibrated size range.
This approach ensures compliance with stringent accuracy requirements for RDE particle measurements and provides reliable data even under dynamic on-road conditions.



Instrumentation

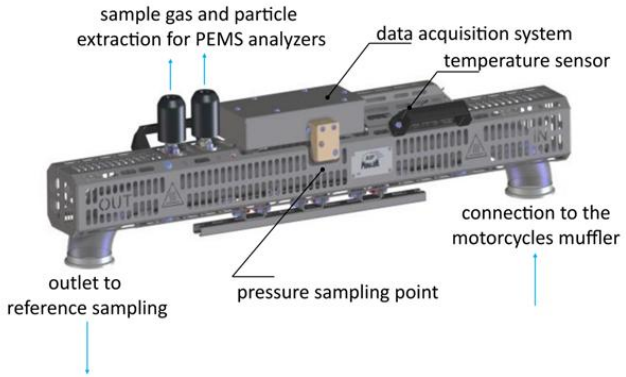
Exhaust Flow Meter

Exhaust Flow Meter (EFM)

The EFM consists of a metal tube with 90° bends and an integrated housing for electronics and sensors. It connects to the exhaust pipe via stiff or flexible metal tubing using V-band clamps. Heated sampling hoses attach directly to internal probes via a quick-lock system, enabling tool-free installation.

The exhaust flow measurement follows the Annubar principle: Differential pressure across a pitot tube is measured by three sensors in cascade for high precision across a wide flow range. Exhaust gas density is continuously calculated using absolute pressure and temperature measurements.

Internal sampling and processing occur at up to 5 kHz, with digital filtering to smooth pulsation effects, critical for low-cylinder engines. EFMs are available in sizes from 1.5″ to 4″. For motorcycles with low exhaust flow, the 1.5″ Low Flow (LF) variant uses a specialized probe for reliable measurement in these applications.



Technical Data: 1.5” Low-Flow (LF) EFM	
Exhaust Gas Temperature	0 °C – 700 °C
Accuracy	2 % of reading or 0.3 % of full scale; whichever is larger
Precision (Repeatability)	≤ 1 % of full scale
Noise	≤ 2 % of full scale
Zero Drift/ Span Drift	≤ 2 % of full scale over 4 h
Measuring Range	0.6 g/s – 57 g/s
Mass	< 6 kg
L x W x H	600 × 150× 300 mm
Electrical supply	24 – 29 V DC | Supply via PEMS

Exhaust Flow Meter Accessories for Flexible Integration

To ensure easy and secure installation of the EFM on a wide range of motorcycles, several accessories are available. The **flexible stainless-steel hose** connects the EFM to the vehicle’s exhaust muffler and is offered in lengths of 300 mm, 500 mm, 1,000 mm, and 1,300 mm to accommodate different setups.
For a gas-tight connection, **stainless-steel clamps** with quick-release knobs are used on both ends of the hose, each including a flat **gasket**. These clamps allow fast and reliable assembly without tools.
Additionally, an **end-pipe weld adapter** ensures a secure interface between the motorcycle exhaust and the PEMS system. This adapter is welded to the test vehicle’s exhaust outlet and comes with a valid ABE, meaning the vehicle’s operating license remains unaffected by this modification.
These accessories provide flexibility, durability, and compliance, making the EFM system easy to adapt for diverse motorcycle configurations while maintaining measurement integrity.

Instrumentation

Exhaust Flow Meter

Validated Exhaust Flow on Motorcycles: Annubar-Based EFM Performance Across Eight Engine Architectures

Accurate exhaust mass-flow measurement is a cornerstone of RDE testing, yet motorcycles pose unique challenges due to strong pulsations, variable gas composition, and even reverse-flow phenomena at low speed and load. In a published study, TUG evaluated our LF-EFM across **eight motorcycles** spanning single-, twin-, and inline-four configurations to determine feasibility, accuracy, and systematic effects in real-world relevant operation.

The EFM under test was the 1.5" Low-Flow, **optimized** for small engines with low exhaust mass flows. It measures differential pressure across an averaging Pitot tube and continuously computes exhaust-gas density from absolute pressure and temperature; sampling and **on-board processing** run at **up to 5 kHz**, with integrated digital filtering to mitigate pulsation.

To benchmark accuracy, all motorcycles have been operated on a chassis dynamometer and drove Validation Cycles which covered a broad operating map, while referencing exhaust mass flow via a CVS dilution tunnel and ECU/OBD channels (e.g., RPM and calculated load). This approach provides a laboratory-grade comparison under dynamic conditions without invasive intake-side instrumentation that could alter engine behavior.

Results show a **strong correlation between** the **EFM and** the **CVS** reference **across all vehicles**: for single-cylinder engines, R^2 typically ranged 0,96–0,98, improving further in multi-cylinder architectures; the inline-four achieved R^2 = 0,99 with a regression slope near unity. These trends reflect smoother exhaust-flow dynamics as cylinder count increases, which reduce the influence of pulsations on differential-pressure measurements.

A deeper analysis revealed harmonic patterns versus engine speed: the EFM captures not only the fundamental blow-down frequency but also overtones, and interactions with resonant modes in the exhaust or probe geometry can produce wave-like error structures that diminish at higher speeds. These findings point to frequency-dependent excitation and coupled gas-dynamic/sensor responses rather than simple load-or-speed effects, what helped us to configure sensor tailored for the needs in motorcycle exhaust assessment.

scattering

Decreased scattering in lower flow regimes

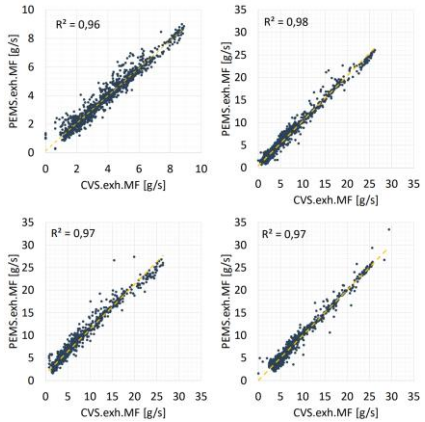
Minimal scattering in higher flow regimes

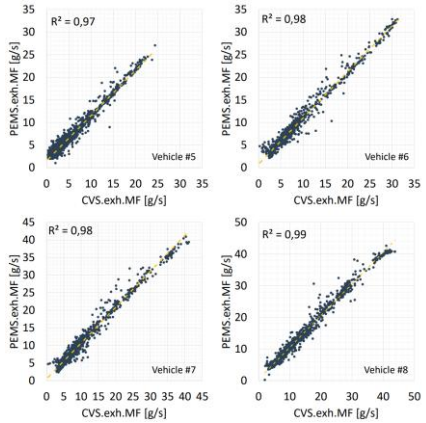
linearity

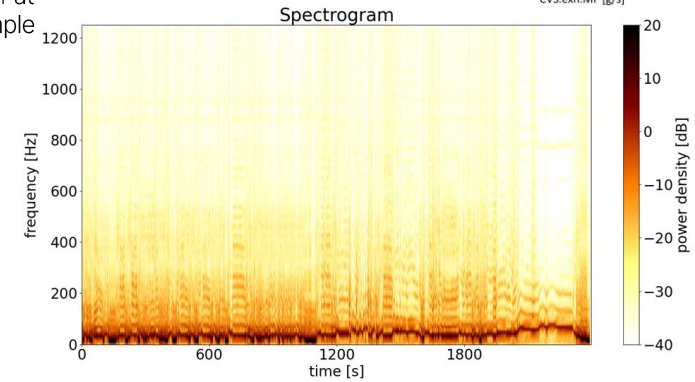
Good linearity through also for engine architecture tested

response

High Frequency Data Processing helped to optimize the system for pulsative flows







[3] Schurl, S., Hafenmayer, C., Lankau, M., Brenn, G., Schmidt, S., & Kirchberger, R. (2025). Overcoming Challenges in Motorcycle Exhaust Flow Measurement: A Study on Measurement Accuracy and Systematic Effects of an Annubar-Based Approach (No. 2025-32-0016). SAE Technical Paper.

Test Procedure

Setup

Pre-Test
- Leak-Check
- PN Zero Check
- EFM Calibration
- Zero Calibration
- Span Calibration

RDE-Ride

Post-Test
- PN Zero Check
- Zero Drift
- Span Drift

Analysis

RDE Test Procedure

Conducting an RDE test on motorcycles requires a structured process to ensure accuracy and compliance with LDV guidelines.

Setup

The procedure begins with system setup and validation, often performed on a chassis dynamometer. This step provides a reference for Moving Average Window (MAW) calculations and confirms proper functionality under controlled conditions.

Pre-Test

Before the on-road test, several pre-test checks are carried out: a leak check to verify system integrity, PN zero check for particle counter stability, EFM zero calibration, and zero and span calibration for all analyzers. These steps ensure that the measurement system operates within its specified accuracy range.

The Ride

During the RDE ride, the test driver receives continuous feedback on the expected outcome of the current test, ensuring that trip requirements and dynamic conditions are met. This real-time guidance helps maintain compliance with LDV criteria and prevents invalid test runs.

The software provides a comprehensive interface that allows the user to perform all required system calibrations and checks, define test parameters, and monitor emission data during acquisition. In addition, it calculates specific emissions on the fly, enabling immediate assessment of test validity and performance.
This capability ensures that both the technical team and the driver remain informed throughout the test, reducing the risk of incomplete or non-compliant measurements and streamlining the overall RDE workflow.

Post-Test

After the ride, post-test validation is performed. This includes a PN zero check and assessments of zero drift and span drift to confirm analyzer stability throughout the test.

Analysis

Finally, data analysis is conducted according to LDV RDE guidelines. This involves generating cyclic and aggregated results, applying the MAW method for pollutant evaluation, validating trip parameters (including dynamic checks such as $v \cdot a_{pos}$), and producing a complete output protocol. These steps ensure that the test meets regulatory requirements and provides a robust basis for emission compliance assessment.

Your path to RDE testing for motorcycles

measured, validated, secured.

AiP

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