A SETUP FOR MEASURING PASSENGER CAR BRAKE DUST PARTICLES EMISSIONS

Martin J. Lehmann, Steffen E. Pfannkuch, Eric Thébault, Andreas Beck
MANN+HUMMEL GmbH
Schwieberdingerstr. 126 – 71636 Ludwigsburg – Germany

ABSTRACT

Every mechanical braking action creates particles through friction between the brake disc and brake pads. These particles contribute to the PM10 emissions of vehicles. The particle generation happens in the short event of braking and depends on brake load and preconditioning of the brake (disc and pads), e.g. temperature, and braking history, to name a few. However, a defined way of generating brake dust particle emissions is the pre-requisite for later validation of filtration performance.

For release of an automotive brake system, specific tests are run at a brake dynamometer. A typical sequence of brake events is defined as AK masters or derived from the WLTP cycle. For particle measurement various techniques can be selected, e.g. DMA, impactor, or particle counter. For reliable data, the integration of such equipment in the air flow through the brake testing chamber is crucial. We briefly describe our measurement setup and discuss what serves as a good first step for evaluation of filtration efficiency.

Focusing on a sequence of AK8 sections provides a good baseline for future evaluation of brake dust particle filters. There is a reasonable amount, of particles generated in the larger particle range of 200 to 400 nm. The standard testing sequence yields quite stable data when averaging over 40 brake events.

KEYWORDS

Air Filter Testing, Air Filtration, Fine Dust, Particle Emissions, Particle Measurement
Motivation

Fine dust particle emissions have become a public topic. One of the most famous examples is the Neckartor at Stuttgart. At this hot spot the concentration of fine dust is now reduced by filters installed by MANN+HUMMEL [(MANN+HUMMEL, 2019)]. Due to the general public awareness of the topic, scientists in Germany have been asked for an ad hoc study regarding clean air (Leopoldina - Nationale Akademie der Wissenschaften, 2019). One of the interesting side notes is that brake dust particle filters, lower emission brake discs, and tires with reduced wear are mentioned as effective solutions for reducing fine dust particle emissions of vehicles.

Brake Dust Particle Filters (BDPF) have been a research topic at MANN+HUMMEL for quite some time (Patentnr. US 9,291,222 B2, 2013). Measuring emissions of brake events is an ongoing task of the UNECE particle measurement program to support the European Union regarding potential future regulations (UNECE, 2019). A recent publication by (Asbach, Todea, Zessinger, & Kaminski, 2019) provides a good reference for measurement of particle emissions caused by braking events. However, there are additional challenges to measuring efficiency of a brake dust particle filter that need to be addressed. Thus, the focus of this paper is on the general challenge of measuring filtration efficiency. We briefly describe the measurement setup, the testing procedures and then discuss initial results. Based on this data a method for testing brake dust filters was derived.

Measurement Setup

Evaluation of a brake system is done with a brake dynamometer. For testing a series of braking events is run. Such sets of braking events are defined for example as AK master (Tab 1). Focusing on brake particle emissions we consider AK8 and AK4.1, AK4.2 and AK4.3 as most relevant ones. Please note, that only for AK8 the braking pressure is fixed at one value. Another set of braking events has been derived based on the WLTP test cycle. This cycle was originally intended for exhaust emissions. The cycle comprises of a number of different brake events. Detecting single brake events and comparing them for various cycles turned out to be quite difficult. This makes it quite challenging to later compare single braking events without and with a filter to derive a filtration efficiency. The AK master sections are however well defined and can be run separately quite easily. Therefore, we picked AK master short (section 8 + 4.1 + 4.2 + 4.3) for further investigations of brake dust particle emissions.
Regarding brake particle emissions, a range from nanometer to small micrometer sizes is expected. Interest in the nature of the particles, as well as count number, caused addition of some measurement equipment for obtaining information regarding particle size distribution. The HORIBA MEXA-2x00SPCS yields particle count, the TSI Dust Track II delivers PM2.5 weighted data. The TSI FMPS 3091 and the TSI APS 3322 provide information regarding size distribution. They are connected by a TSI flow-split to the same sampling position. The alignment at the transition point is done offline. The gravimetric measurement by an absolute filter yields the mass collected during the testing period.

The flow path in the enclosure of the dynamometer was visualized by CFD simulations (Fig. 1). The CFD simulation shows a somewhat focused flow around the brake. This is a good reason that most particles are carried with the flow. However, since there is no specific flow guidance installed there might be some particle loss. But this should be quite similar with and without an installed brake dust particle filter. Consequently, for comparing the two installations to derive an efficiency, the error should be similar and is therefore initially neglected.
Pre-test, were conducted to finalize a good sampling position. Regarding the indicated sample position (Fig. 1), the CFD simulation mistakenly shows an unstable flow. Because the focus was on the proximity of the brake and also due to simulation speed, some flow guiding devices have been omitted. The position marked is at the standard outlet for the HORIBA MEXA. This turned out to be a promising position for filtration measurements, due to the particle count being high enough to later detect an effect of filtration, as well as the background noise being lower than next to the break.

**Results**

In a first step, we compared our test results with published data (Asbach, Todea, Zessinger, & Kaminski, 2019). For that purpose, we run the WLTP cycle. The particle sizes measured show a similar distribution (Fig. 2). As the known values differ for each WLTP cycle. This indicates that the WLTP cycle might not be a preferred one for comparing measurement without and with a mounted brake dust particle filter. But the results demonstrate that our setup yields similar results as published.
Next, we measured the particle size distributions for the AK master short subsection AK8, AK4.1, AK4.2 and AK4.3. The results are shown in Figure 3 as counts measured during the subsection duration. For the AK 4.x sections the braking pressure varies. For AK8 the braking pressure is always the same. Compared to AK8 there is an additional peak for particles of 10 nm in sections 4.2 and 4.3. Sections 4.2 and 4.3 are starting from 80 km/h respective 120 km/h and the temperature various with braking pressure. With higher temperature at the brake, there is a chance for evaporation and nucleation leading to small particles of the 10 nm peak. This is not observed in a significant amount for the 4.1 section closer to urban driving (starting at 40 km/h).

Fig. 3 – Particle size distribution measured for AK master short subsections. Each section was run five times. Averaged values are shown.
For evaluation of a brake dust particle filter, the level of particle counts needs to be high enough to later detect even small numbers of reduction. As the AK 4.1 shows quite low numbers of particle counts in general, this might not be the best option for reliable testing of a brake dust particle filter.

Changing conditions during a test cycle are not favorable for reliable testing regarding filtration performance. Due to the variance in braking pressure the sections 4.2 and 4.3 are discarded. The AK8 section provides a reasonable high level of particle counts for the 200 to 400 nm range and is defined with a constant braking pressure. Both make it a favorable option for testing a brake dust filter. However, AK8 section is missing the peak at 10 nm. But these smaller particles contribute less to the PM10 emission. Therefore, as the first choice we selected the AK8 subsection as test procedure for a brake dust particle filter.

Reproducibility and low variation of particle counts are required for testing filtration efficiency of a brake dust particle filter. In the first series the base emission of the brake needs to be measures. Then the filter is mounted and the reduction of emissions is measured. The comparison gives the efficiency. We then studied the variance of the particle counts during one series of AK8 subsections (Fig. 4). The single braking events show quite a scattered picture of particle counts with standard deviation of 30 % to 40 %. However, averaging all braking events of an AK8 section results in a very reliable value. The deviation between different AK8 sections with 40 plus braking events turned out to be about 15 %. Therefore, we decided to use the average value for comparing measurements with and without filter.

![Fig. 4 – Particle counts of single brake events as sequence of AK8 section measured with HORIBA MEXA.](image)

**Conclusion**

The standard testing setup at a dynamometer was investigated with regard to future measurements of filtration efficiency. As the filtration of a brake dust particle filter is calculated based on measurement on an installation without a filter compared to an installation with a filter, the measured particle numbers should be reproducible and variance should be small. A first setup and initial procedure for measuring particle filtration
efficiency of a brake dust particle filter has been defined. The best sampling position found is at the downstream pipe at the same sampling outlet as for the standard MEXA measurements at a HORIBA test rig. A position close to the brake (and later brake dust filter) was discarded not only due to high background noise.

Similar particle size distribution was measured as published for WLTP cycle. For reliable and reproducible particle generation of brake events the AK8 master has been selected. While single brake events scatter, the average value of a series of 40 plus braking events turned out to be quite stable with about 15 % deviation. This sequence will be used for evaluation of the filtration efficiency of a brake dust particle filter.

Outlook

The next step is measuring an installation with and without a filter. Comparing the averaged values of the AK8 sections will yield the filtration efficiency of a brake dust particle filter. Results will be presented at the World Filtration Congress. The question is, what efficiency would be a good one? A look at the regulated exhaust emissions might give some reference. According to (Timmers & Achten, 2018) a typical PM10 fine dust emission coming out of the tail pipe by exhaust is about 3 mg/vkm (vkm = vehicle kilometer). A typical PM10 emission by brake wear is about 9.3 mg/vkm. Compensation of the exhaust emission by a reduction of the same amount due to less brake wear, could be an interesting target. An efficiency of 32.3 % would already mathematically neutralize the exhaust PM10 emission. This would show the internal combustion engine at a similar regulated PM10 emission level than electric vehicles as regulated exhaust emissions are compensated by brake wear reduction.

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Literature


