AN APPROACH TO LOWER THE PARTICLE EMISSION OF FRICTION BRAKES ON VEHICLES

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ABSTRACT

Friction brakes and tires are the main emitters of micro- and nano-particles in road vehicles next to the internal combustion engine. Possible impacts of brake dust on the environment and human health were reviewed in previous studies [1-2]. The typical composition of friction brake linings [3] encompasses materials like metal and metal oxides of copper, iron, aluminum, zinc and sulfides. As shown in Figure 1, the particle size of brake dust particles is larger but comparable to diesel engine emissions.
Combined with the already mentioned materials in brake pads this could be an underestimated threat to the environment and the human health [4].

1. INTRODUCTION

According to experimental data from a friction material developer as well as from other studies, mentioned in a report of the German Federal Department for Environment [5], the amount of airborne dust generated by brake wear can reach 15-31 mg/km for passenger cars (lower values for low steel pads), 66-90 mg/km for lorries and > 100 mg/km for buses in urban areas. A recent literature review [1] of the Institute for Energy and Transport of the European Commission reports PM_{10} (particles smaller than 10 µm) brake wear emission rates of up to 8.8 mg/km and $PM_{2.5}$ rates (particles smaller than 2.5 µm) up to 5.5 mg/km for passenger cars. For reference, the Euro 5 and 6 regulations for diesel engines set a limit of 5 mg/km for PM_{10} measured for exhaust. Thus, there is a potential for reducing the overall air pollution by reducing brake emissions.

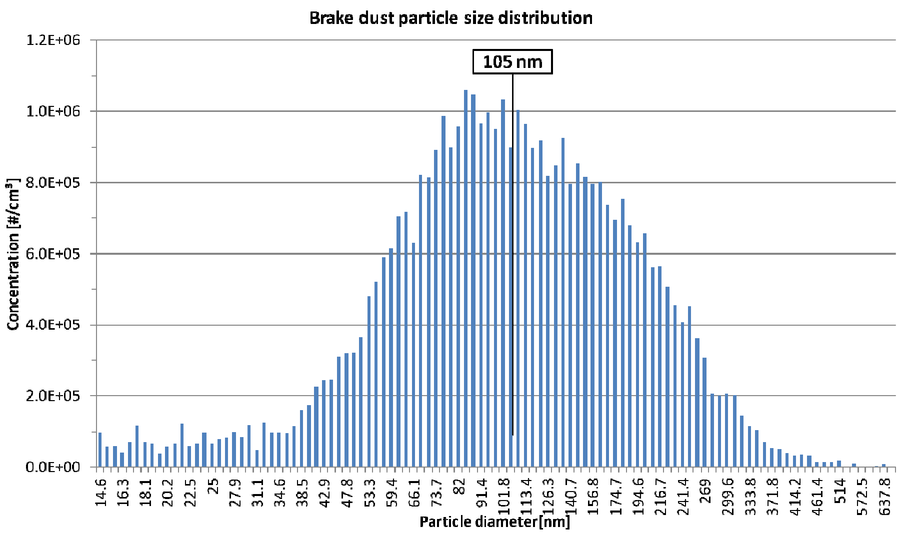

Figure 1: Brake particle size distribution

It concerns both PM emission and particle number (PN) emission from brakes; the EU is currently the only region worldwide where PN emission standards for vehicles are in place [6]. Development of low-emission brakes with reduced negative impact on the environment and human health are therefore urgently needed. This is supported by the wealth of data on the relationship between particle exposures and adverse human health effects and the notion that not all particles are equally toxic. Current and expected regulations can promote innovative brake design and brake system components.

2. BRAKE PARTICLE MEASUREMENT

First step to analysis the particle problem of the friction brake is the particle measurement. This subject has gained a lot of interest since the introduction of diesel particle filters. Since the technique and feasibility of particle detection has increased, other particle sources are pushing in the focus now. Figure 1 is also an explanation for this development. Without the highly accurate and high resolution particle sizer there would not be enough information beside the chemical formulation of brake pads that brake dust is hazardous. Previous particle counters and sizers belong to the group of photometers or optical particle counters (OPC), which can based on their operating principle only measure particles larger than 100µm and some only above 300µm. Since the development of systems like the HORIBA SPCS (solid particle counter system) it is possible to detect particles reliable above 23nm (legislation reasons).

The tests are carried out in a brake dynamometer at the TU Ilmenau. This dynamometer delivers laboratory conditions for repeatable brake emission measurement. Under these conditions it is possible to compare influencing factors on brake emissions, e.g. brake pad formulation, history of previous braking with the friction partners or actuation profile and many more (see Fig. 2). Brake testing always is carried out with at least the complete brake system with a set of brake pads, a disc and a caliper mounted on the wheel hub. For brake dust measurement it is possible to carry out the tests with a wheel rim to include swirl effects from the wheel design.

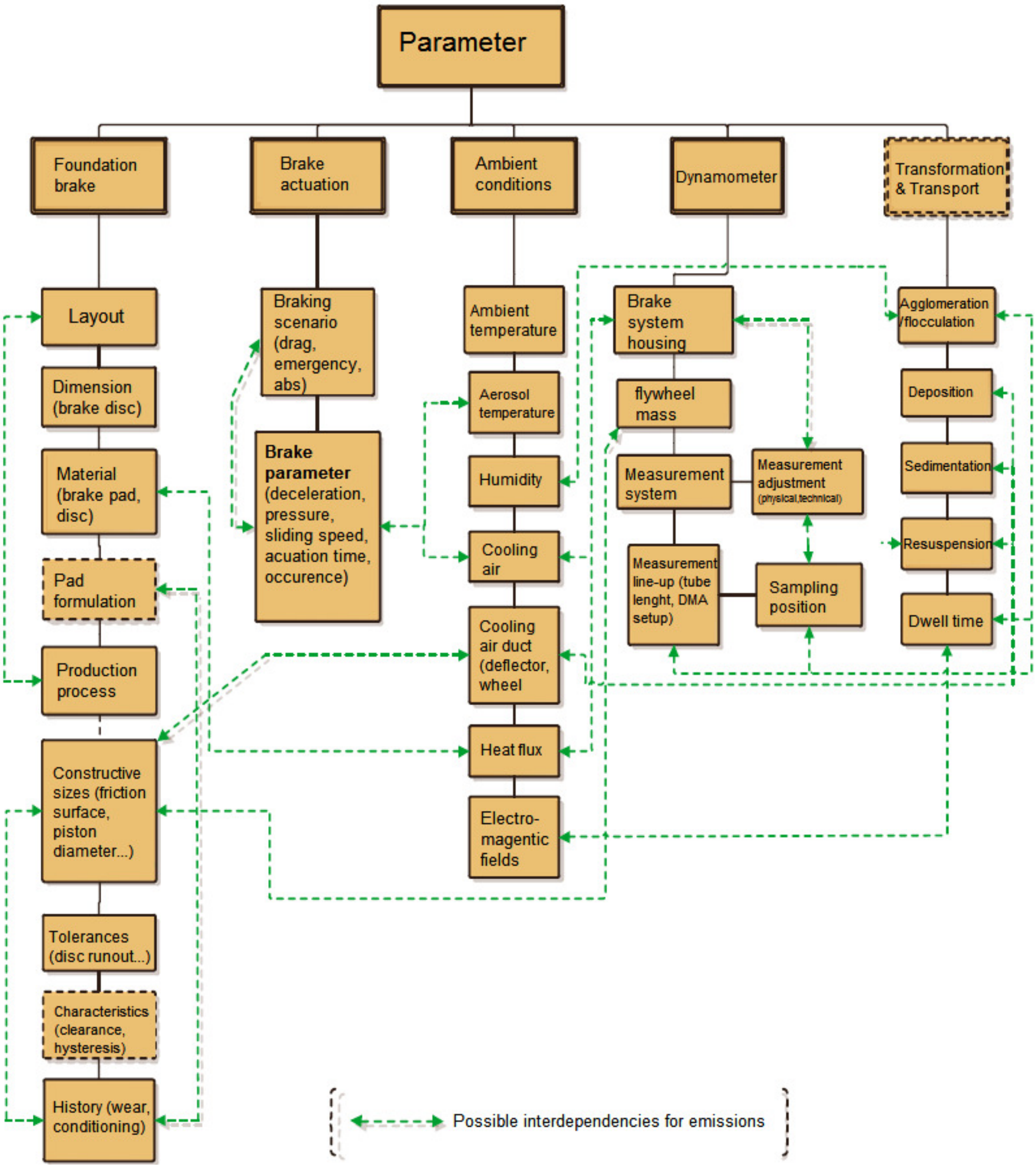

Figure 2: Influencing factors on particle emissions from the brake [8]

The next challenge to characterize the particle emission of brakes is choosing the sampling point near the brake system at the wheel hub. From previous research with visualization techniques (Particle image velocimetry, [7]) it is known where the air stream around the brake is carrying the wear particles. Because of their negligible weight compared to the volume, the debris tends to follow any air stream. This is the reason why it is problematic to measure brake dust during the usual test cycles for brake material, because in these tests cooling air is mandatory. Knowing the approximate sampling point near the brake system, it needed several tests to find the optimum (Figure 3).

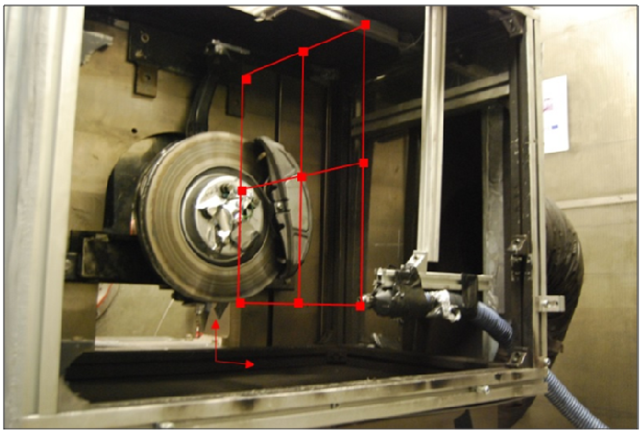

Figure 3: Dynamometer brake emission measurement

After the parameters were fixed, the comparative measurements could be started. It could be proved that a green (new pads and disc) friction system emits a higher amount of particles until the friction level is stable. The reason is that the friction surfaces of pad and disc have to adapt to each other until the system works as intended. That means higher abrasion of the raw surfaces from the production process. This happens at least during the first 40 brake actuations, depending on rotational speed and brake pressure. When the friction system is stable there are a lot of further particle emission parameters as mentioned before. The next very relevant factor is the comparison of different brake pad formulations like ECE and NAO. ECE means that the pads fulfill the European legislation for demands on brake systems. This ECE formulation is made for high friction levels because in Europe there are roads with high speed limits or no speed limits which require also high temperature stability. NAO stands for non asbestos organics and were initially made for the Asian market which demands long lasting and quiet brake components. Therefore a trade-off with the friction level and the temperature stability is accepted; in this aspect the NAO cannot deliver the performance of the ECE. The particle emission of these two formulations is according to these characteristics. The tested ECE pads emitted 300% more particles (PN) in average compared to the NAO in the same city-like test cycle (braking from 50km/h to still stand with 0,25g deceleration). In a countryside highway cycle the emission difference gets lower but the ECE still emits about twice as much particles than the NAO. This advantage of the NAO turns into negative until we use conditions like brake actuation at 150km/h with 0,4 g decelerations until the brake disc reaches 300°C. At this point the NAO starts to deteriorate because it is not designed for such use. This is the reason why the change of ECE to NAO is not a solution for the particle problem of the brake, but it shows a possible direction. Some automotive suppliers have already launched hybrid brake pads on the market which fulfill demands for a pad with properties between ECE and NAO.

Measurement on test benches is crucial to evaluate the parameters of brake dust emissions but it is only an attempt to analyze the process that is working in the real vehicle on the road. For this reason it is essential to measure emissions on the vehicle during usual road driving. RDE (real driving emissions) is an issue that has an increasing attention in the exhaust gas measurement, but on-board particle measurement systems that can detect emissions in the nano range are not market-ready yet. Because of that lack, a portable system was compared to the SPCS on the dynamometer to validate the results. The sampling point of the portable system in the vehicle was placed directly behind the brake caliper to minimize effects from other particle sources like exhaust particles and road dust dispersed by other cars. The test vehicle was equipped with a sensor for brake pressure in the front brake, so actual braking can be ensured and compared to other occurrences.

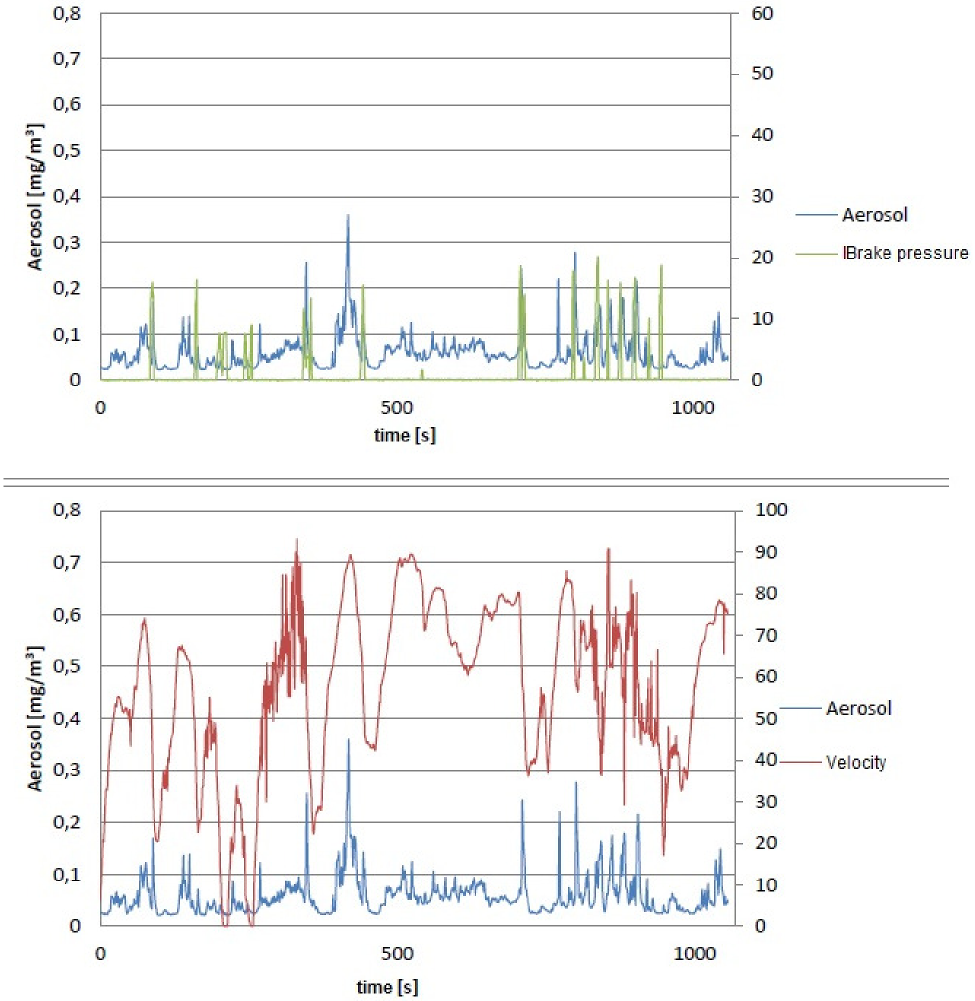

Figure 4: Data from RDE measurement for the brake

Figure 4 shows an excerpt of the brake particle counting during road driving. Some brake actuations generate peaks for particle emissions, but other emission peaks do not shows any match with the brake signal and have to originate from other emitters than the brake. Therefore it is necessary to monitor the display of the measurement system and note time and possible reasons for non-brake emission detection. This test procedure allows the proof of particle reducing methods on the brake system, since it is not under reality falsifying laboratory conditions.

3. REDUCING PARTICLE EMISSION

Knowing the influencing factors on brake dust emissions and how to measure the impact of changed parameters, it is possible to systematically search for measures to reduce the particle emission. This can be done in different ways on the brake e.g. change in formulation, collect the particles or change their physical properties in a way that makes then less harmful.
As mentioned before, the change in formulation of pads or even disc is possible but immense difficult with a time-costing way to solve several conflicts of aims.
One possible low-emission design measures with collector principle as shown in Figure 5 was already tested on the brake test bench at the TU Ilmenau. As already mentioned, the fine dust tends to follow any air stream, so it is feasible to install a collector with additional tubing and

air ventilation to guide the particles into a filter medium. Experiments on the dynamometer showed a significant high reduction of particle emission outside the wheel hub.

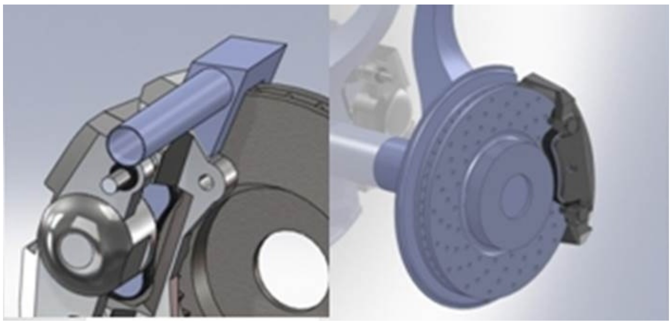

Figure 5 Brake dust particle collector

Another possibility to reduce brake dust or at least lower the amount of the fine dust is the machining of the friction surface of brake discs. The exact function principle is not proven yet but the effect was shown on dynamometer and road tests. One explanation is that brake wear in the friction zone is collected inside the holes or slots on the surface. When the cavities are rotated outside the friction zone and the brake caliper, the agglomerated particles with higher weight to surface ratio are thrown to the inside of the wheel rim where they are collected (Fig.6). This does not solve the initial problem of emitted debris but it makes it less harmful.

Figure 6: Wheel rim of surface machined disc (left) and standard disc (right)

4. CONCLUSION

Brake particle emissions are gaining attention since it becomes clear that these emissions rise above the level of modern cars exhaust emissions. The measurement systems can be adapted from exhaust gas monitoring but the testing facilities and the setup is very different and a novel field for research. It was shown that measurement on the dynamometer under laboratory conditions and real driving emission measurement in combination is needed to verify changes on the brake system. Possible ways to reduce the emissions from the brake can relate all assembly parts of the wheel hub and the brake. Pad formulation or disc composition can be optimized but this is a complicated conflict of aims with other demands on the brake system. Collectors are very effective but an additional cost factor which also needs building space inside the wheel rim. Surface machined discs do not solve the initial problem of the produced amount of particles but makes them less harmful.

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