Numerical and Experimental Studies of uncertain Parameter for Brake Noise

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Abstract

The quality of a brake system is nowadays defined by performance and mainly by the occurrence of noise.

The aim of every brake manufacturer is to reduce this kind of noises, especially the so called brake squeal. Squeal is a noise which occurs at some constant frequencies that differ from brake to brake, the frequencies can start at 1 kHz and go up to 16 kHz, the sound level can be up to 110 dB(A).

The Robert Bosch GmbH has an NVH department for solving these noise problems inter alia, NVH stands for Noise Vibration Harshness.

The process of noise reduction consists of two parts: the simulation of the brake with all of its components and the experiments with the real brake. So on the one hand we build up a simulation model of the respective brake with a lot of uncertain parameters. On the other hand several tests are performed to extract the responsible parameters for squeal noise. To get repeatable results the tests were conducted on special test benches. By keeping the boundary conditions as constant as possible (e.g. the bolt torques after changing parts or the microphone position) a couple of input parameters like temperature or humidity are varied controlled. The problem is that we have just a limited number of parts and every change of for example the brake pads means a change of the input parameters.

The challenge is to define the number of test and set up a matrix of the input parameters which will vary and their variations and to include them in the simulation model.

Because every brake is unique, the whole process has to be done for every single brake. That is why we try to find a systematic way to shorten the process and to improve the simulation with the uncertain parameters.

1 Introduction

The main objective of this paper is to describe the procedure of getting a complete brake squeal simulation.

What is necessary to build up and validate a simulation model and which experiments need to be done to achieve go correlation between the simulation and the real brake? Experiments on test benches are made to detect brake squeal and to find parameters which lead to an increase of this noise. Then the parameters will be included into the simulation process and varied with the help of fuzzy algorithms.

2 Brake Squeal

Brake squeal is a self-excited friction-induced oscillation. As described in [1] and [6] the mechanism of squeal is mode coupling. Two stable modes of the disc (normally a radial in-plane and a bending mode) are getting closer to each other with increasing friction coefficient and get coupled at a critical μ, this leads to one instable mode (see figure 1a) which is audible as a squeal with a sound pressure level up to 110 dB.

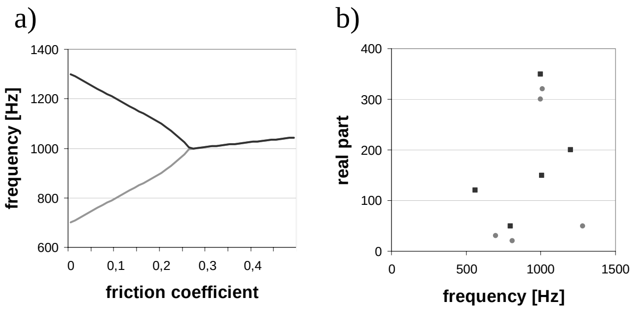

Figure 1: a) mode coupling, b) simulated instable modes

In the simulation the noise index is the magnitude of the positive real part of the complex eigenvalue (figure 1b). It indicates the initial growth rate of a particular mode, but its magnitude does not necessarily indicate the noise level or noise occurrence rate.

3 Simulation details

The process of simulation starts with meshing the CAD-model components and making a modal analysis of each of them. Simultaneous the brake hardware parts gets analysed via experimental modal analysis (EMA) using a three dimensional laser scanner to obtain their modal characteristics. The results of these analyses will be compared to each other and the material parameter of the CAD-model will be updated till correlation is reached. The CAD components as well as the hardware parts are then assembled stepwise up to the complete brake and are again compared to each other to update the interface parameter. Subsequently an experimental modal analysis under operational conditions (EMA-OC) will be performed with the hardware. The mounted brake (in the car or in a special fixture) will be analysed under working means driving and braking conditions, therefore the disc rotates and stepwise a brake pressure will be applied and increased (see [1]). The last experimental step for validating the simulation model is the execution of a modal analysis under squeal conditions the so called operating deflection shape measurement (ODS) as described in [4].

Following [5] the three steps of the simulation start with calculating the static equilibrium of the system in a non-linear analysis. Here pressure will be applied on the brake pads to get the pre-load deformations and pressure distributions. The second step is the linearization at this equilibrium point. Finally a linear complex eigenvalue analysis (CEA) is performed to investigate the system instabilities. The disc rotates virtually and different brake pressures, velocities and friction coefficients are defined.

During this study we want to include more than these three parameters, for example the length of the pads or thickness of disc and pads, and determine them with the help of fuzzy arithmetic.

4 Test equipment description

To get the uncertain parameter for the simulation we make a fingerprinting of each brake component where we measure the geometry, the eigenfrequencies, the weight and (for the pads only) the compressibility. This is made before each test and afterwards to evaluate wear too.

The experiments are performed on special test benches, called inertia dynamometer, where the brake is mounted in a car simulating fixture as seen in figure 2.

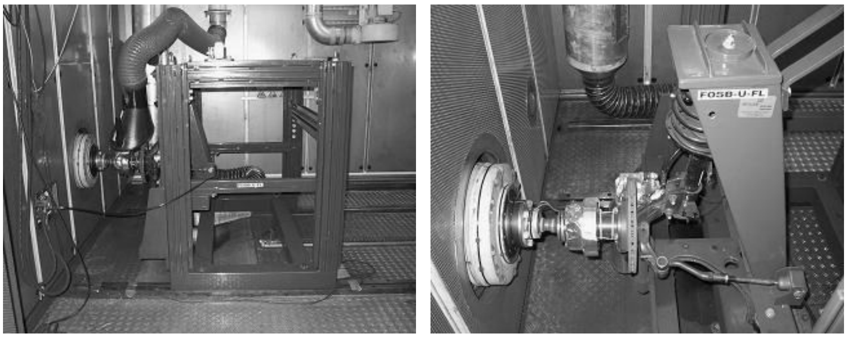

Figure 2: brake mounted in the test bench

The dynamometer consists of two chambers, one with an electric motor that provides kinetic energy to inertia flywheels that simulate the inertia of the vehicle and one sound insulated where the brake is tested (see [3]). The noises are recorded by a microphone which is located at a fixed point near the brake. Different sensors (for example for disc, brake and air temperature as well as humidity) are placed in and around the brake. The dynamometer gets programmed for the test with the information of the car, the brake and the test procedure and gets started manually, after that the test runs automatically.

5 Test programme

Here we run an SAE J2521 test which is developed to drive to most critical settings to detect squeal. It is a matrix consisting of a mixture of drag brakes and stop brakes after a warm up phase. Different brake pressures, velocities, driving directions and maximal brake temperatures are combined (figure 3). These modules have a different length, meaning a different number of stops, and are repeated 3 times. The whole test consists of 1430 stops and takes dependent on the set sampling rate of the microphone up to 26 hours.

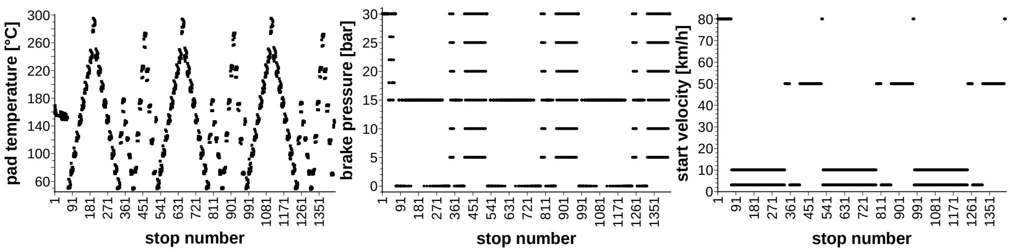

Figure 3: SAE J2521: temperatures, brake pressures and start velocities

6 Evaluation of the tests

As shown in figure 4a as result of the tests we get the squeal frequencies and their associated noise niveau. We can contrast them to our brake conditions like pressure and velocity (figure 4b and c) and see which parameter values we have to define in the simulation. Because in the simulation only drag stops are possible, we also take our emphasis on these modules.

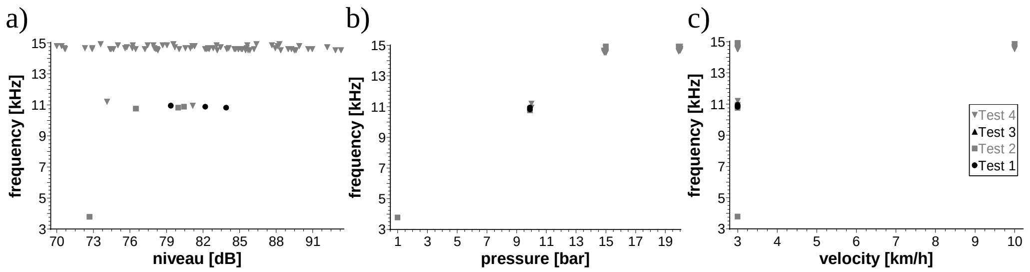

Figure 4: diagrams as visualisation of test results (four example tests)

One important point for a brake is the friction coefficient. During one stop the coefficient varies in a rage that can differ a lot, as seen in figure 5 and 6.

During one CEA just one value of the coefficient can be defined so it is important to take a close look at the evaluation of this parameter. We can not just take the mean value but have to calculate more than one CEA to check the influence of the friction coefficient.

The next step is to look at the influences of the different parameters on the squeal intensity and include important parameters into the simulation model and vary them.

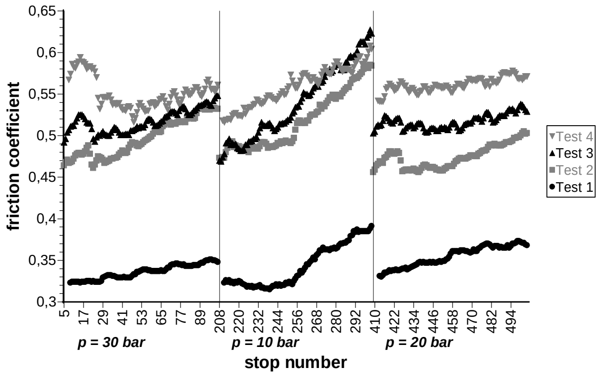

Figure 5: friction coefficient for 3 drag stops

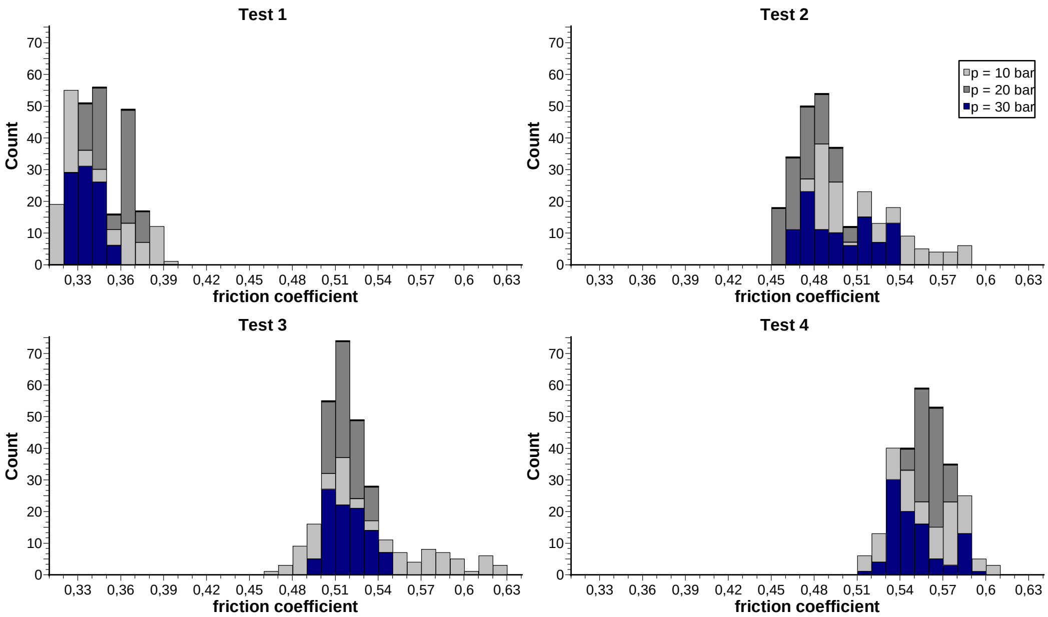

Figure 6: histograms of the friction coefficient for the 3 drag stops

7 Conclusion

The quality of a finite element model is limited by the accuracy of the parameters used and it is always necessary to regard the system under operational conditions.

After evaluating the squeals with experiments and finding the varying parameters they have to be included in the simulation. The variation with the help of fuzzy algorithms may show a direction for new tests with till then unknown values of the known parameters to increase the squeal occurrence or noise level.

2 References

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