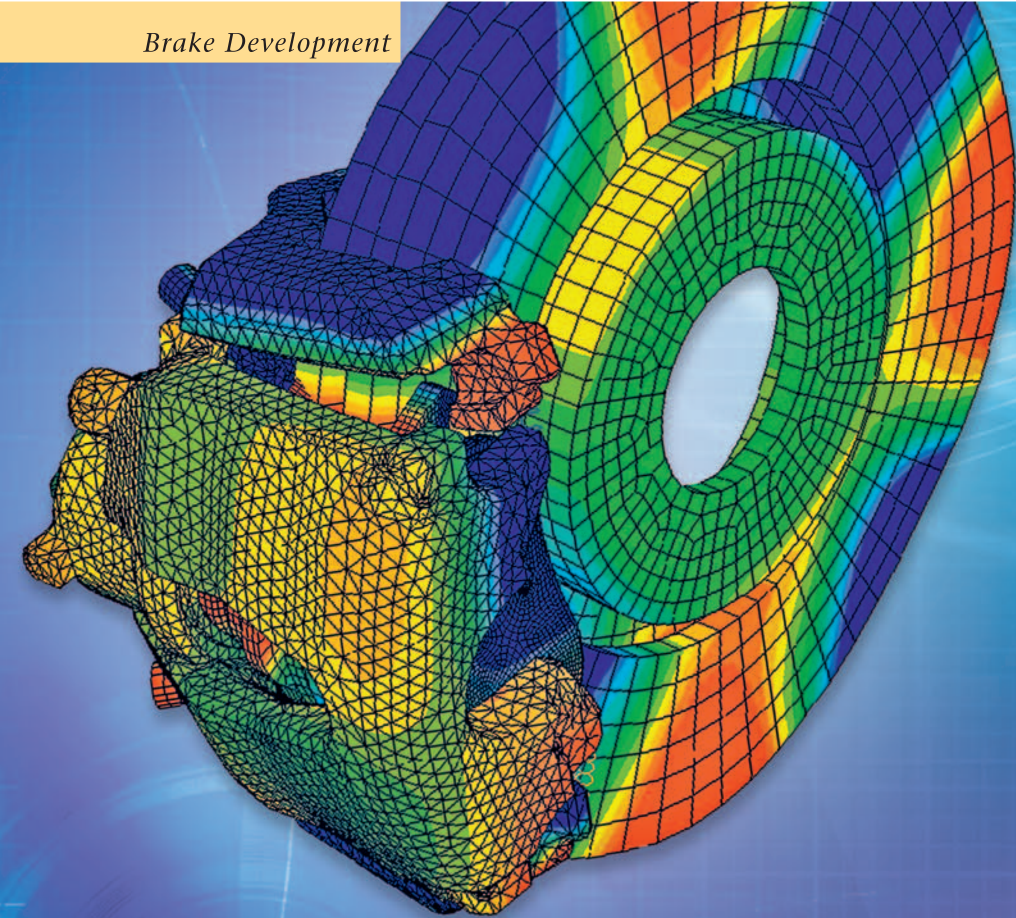


Computer-aided simulation of brake noise has made impressive advances in the past few years. Likewise, 3D scanning vibrometry has substantially extended the possibilities of experimental vibration analysis. Scanning Vibrometry enables the measurement of both in-plane and out-of-plane operational deflection shapes of the relevant components in the same test setup. At Continental Automotive Systems the measurement of brake systems with scanning vibrometry including PSV-400-3D systems is fully integrated in the design optimization process to specifically avoid brake noises.

Quiet Please!

Eliminate Brake Squeal with Numerical and Experimental Vibration Analysis

Finite Element Simulations

Brake noise is an important concern in developing brake systems. Brake squealing is still the most frequently cited NVH concern. It is caused by self-excitation and includes usually just one frequency. The noise appears when certain temperatures and pressures are attained in the brake system. A first optimization to prevent self-excitation consists of a complex eigenvalue analysis with subsequent structural modifications to avoid unstable modes. The analysis is based on the vibration equation

$$f(t) = M\ddot{q} + D\dot{q} + Kq = 0$$

where $f(t)$ is the force, M is the mass matrix, D is the damping matrix, K is the stiffness matrix and q is the displacement vector. Continental Automotive engineers simulate the complete brake system with all adjacent components featuring several hundred thousand degrees of freedom. On the one hand, the complex Eigenvalue analysis can be started during the design process without any prototypes necessary. On the other hand, the method is too sensitive and shows more squeal frequencies than actually exist. Therefore, it is necessary to compare the results to simulation and dynamometer testing and verify whether the calculated ODS actually occur in practice. In Figure 1, the calculated operational deflection shape of a squealing brake system is shown.

Experimental Data

In Figure 2, the test setup for measuring the operational deflections shapes with a 3D Scanning Vibrometer on the brake test stand is shown. The scan measurements are triggered when the brake brake squeal is detected by a microphone.

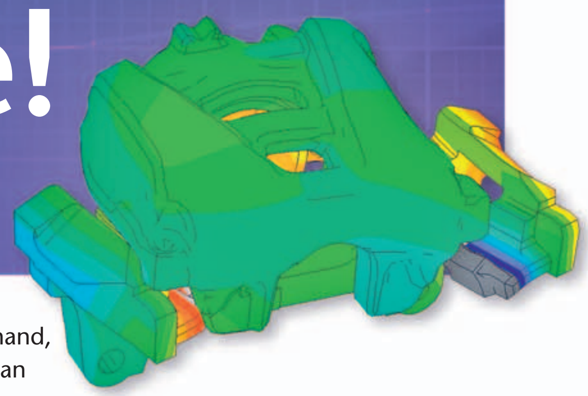


Figure 1: Calculated ODS (operational deflection shape) of a squealing brake system.

Figure 2: The setup of the 3-D Scanning Vibrometer to measure the operational deflection shapes of the brake caliper and rotor.

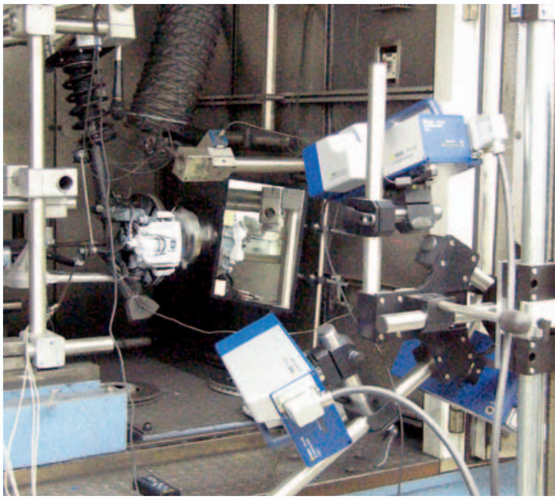


Figure 3: Operational deflection shape of a brake caliper measured by the vibrometer.

This guarantees that acquired data is correlated to specific sound behaviors.

The vibration behavior of the brake system is measured simultaneously from three different directions.

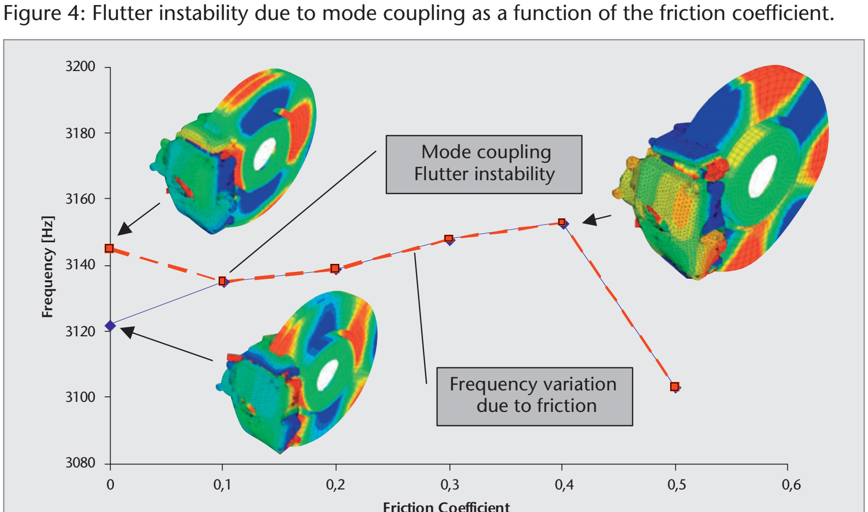
Instead of moving the sensor heads and stitching together the measurements from the different positions, surfaces not directly accessible from the sensor position are measured via mirrors. When measuring via mirrors, a coordinate transform of the measurements is necessary to make sure that all measurements both with and without a mirror are displayed in the same coordinate system. This is enabled automatically by predefining the mirror positions during the setup of the Scanning Vibrometer. In Figure 3, the operational deflection shape of a brake caliper measured with the Scanning Vibrometer is shown.

Extending the measurement to three dimensions, the 3D Scanning Vibrometer has become an essential tool to collect experimental data for the optimized design of brake systems. It enables the measurement of both in-plane and out-of-plane operational deflection shapes of the relevant components in the same test setup.
In contrast to conventional measurements with tri-axial accelerometers, it enables fast and efficient non-contact and thus reactionless measurements at all optically accessible surfaces, while simultaneously increasing the number of measured points. An integrated distance sensor known as the Geometry Scan Module enables acquisition of the 3D spatial coordinates on a predefined measurement grid. If available, geometry data can also be imported from a FEM program.

Supression of Unstable Modes

As soon as the operational deflection shapes and mode shapes are known, the causes of self-excitation can be elucidated on the basis of mode coupling. In Figure 4, the interaction of two modes of the brake system (caliper and brake disk) are shown to depend on the friction coefficient. The dashed red line shows the frequency of one mode, the solid blue line the frequency of a close second mode.

Figure 4: Flutter instability due to mode coupling as a function of the friction coefficient.



Polytec Product Information

PSV-400-3D Scanning Vibrometer

The PSV-400-3D Scanning Vibrometer is the perfect measurement instrument for gathering 3-dimensional vibration data from both simple and complex structures. It features an intuitive 3-D animation of the measurement results with separation of out-of-plane and in-plane vector components as well as a powerful data interface to Modal Analysis and FEM Software.

www.polytec.com/psv3d

By increasing the friction coefficient, the frequency of both modes are changed. At first, the frequency of the first mode is decreasing while the frequency of the second mode is increasing until the frequencies of both modes are the same at a friction coefficient of 0.1.

In this case both modes are coupled and result in a flutter instability as a result of interaction between caliper and brake disk. When increasing the friction further, the two modes remain coupled. In order to eliminate the brake noise, the structure is modified by shifting the resonance frequencies so that the mode coupling disappears.

Summary

The analysis of mode shapes based on experimental data acquired with a 3D Scanning Vibrometer enables selective brake design modifications to avoid brake noises.

Holger Marschner, Continental Teves AG & Co. oHG, Frankfurt a.M., Germany
holger.marschner@contiautomotive.com
dirk.reckwerth@contiautomotive.com