BREAKTHROUGH FOR BRAKE DESIGN

New method simulates brake-squeal problems early in the design process.

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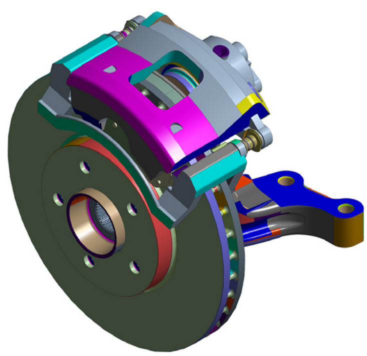
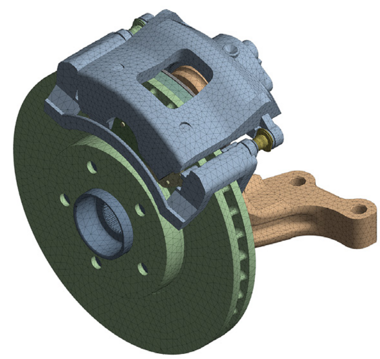
Friction-induced brake squeal has been a challenging issue for the automotive industry for decades; it has become particularly important today as other sources of noise have been reduced or eliminated. TRW and other brake producers previously relied on a brake-squeal simulation method in which interfaces between brake pads, rotors and other components were manually modeled prior to performing structural analysis. The weakness of this approach is that it requires assumptions of how the components contact each other that then must be validated by physical testing. This takes considerable time and money, and delays the product development process.

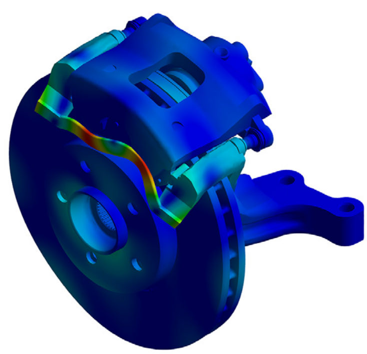
More recently, TRW has validated a new method that uses ANSYS Mechanical software to establish the initial contact and compute the sliding contact between the pads and the disc. Simulation studies have determined that this approach accounts for system contact conditions, enabling brake noise to be simulated and reducing the need for physical testing to tune the models. The entire simulation process is contained within a single environment, which saves time by automating many aspects of the process and setting up batch runs for design optimization or manufacturing variation analysis. This method has made it possible to design and build quieter brakes in less time than is possible with traditional methods.



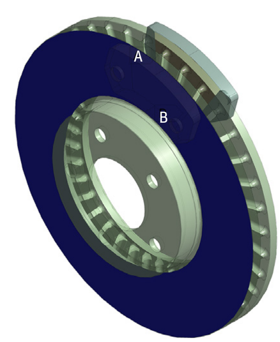
Typical TRW brake system, with disc rotor (green) and ventilation slots around perimeter. The caliper (adjacent pink and grey sections) houses the brake pads, which are visible through the inspection hole. The caliper mount (teal and grey) and steering knuckle (blue) also are shown.



Tetrahedral mesh on disc rotor (green), caliper and caliper mount (both grey), and steering knuckle assembly (tan)



Visualization of complex eigenvalue for unstable mode. Contours of relative deformation on the caliper mount (yellow, red) have been scaled up for clarity.



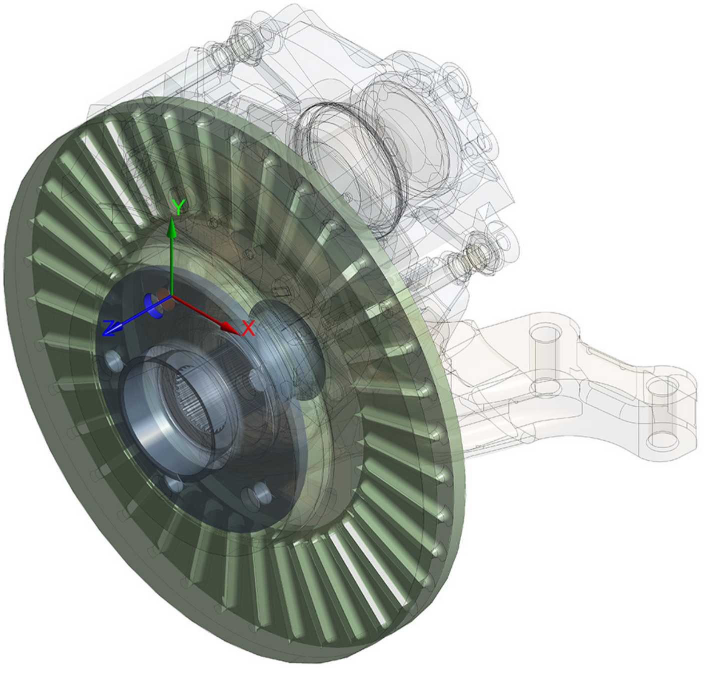
Cutaway of brake pads and disc rotor highlighting one of the frictional contact pairs (marked A and B) between the rotor and one of the brake pads

CHALLENGE OF SIMULATING BRAKE SQUEAL

Researchers have estimated that noise, vibration and harshness, including disc brake squeal, generate warranty costs of about $1 billion a year to the automotive industry in North America alone. At least $100 million of those expenses can be attributed to brake squeal. Automobile suppliers and original equipment manufacturers stand to benefit if they can identify the potential for a proposed design to squeal early in the process, before millions of dollars have been invested in detailed design, prototyping and manufacturing tooling. Since it is not feasible to produce every single component to exact dimensions and material specifications, it's important to determine whether the small variations that are inevitable in the manufacturing process will cause a percentage of production builds to squeal.

Although all brake squeal causes are not fully understood, it is commonly accepted that such noise is initiated by instability due to the friction forces, leading to self-excited vibrations. This process is inherently more complex than a typical simulation problem that consists of applying a measurable load to a structure. Simulating brake squeal has typically required a tedious mesh generation process of manually creating couplings between the brake pads and discs. Dynamic analysis is used to analyze the eigenfrequencies of the system to determine whether or not squeal will occur.

A big weakness of this method is that factors such as deflection may change the way that the pad and disc surfaces come together. They may contact each other at an angle or with greater or less force than is expected. With the traditional method, the uncertainty in the contact conditions is addressed by building and testing a physical prototype and comparing the measurements against simulation predictions to tune the model. The first try is often a poor match, necessitating that the simulation be run over and over again, adjusting the contacts each time until the predicted results accurately match the physical tests. This approach is both expensive and time-consuming.



One of the joint interfaces between rotor and hub

TRW engineers wanted to accurately simulate brake squeal without having to spend extra time and money on validation testing.

DEVELOPMENT OF NEW SIMULATION METHOD

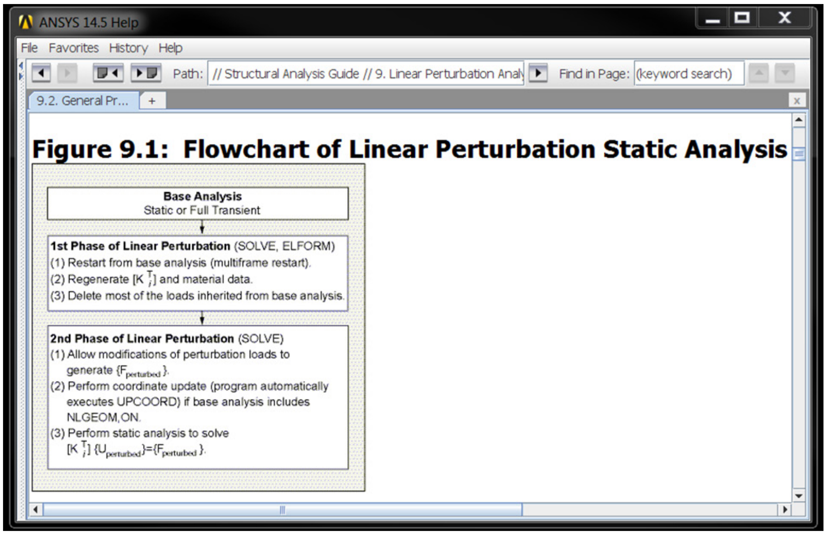
TRW's engineers wanted the ability to accurately simulate brake squeal without having to spend extra time and money on validation testing. The TRW team worked with ANSYS technical services staff to accurately define contact conditions prior to physical testing by using a nonlinear static solution to establish the initial contact and compute the sliding contact between pads and disc. ANSYS software enabled the entire brake-squeal simulation process to be incorporated within the ANSYS Workbench environment, which allowed automating the ability to simulate expected manufacturing variation and determine if the design met robustness requirements.

The new simulation process — jointly developed by TRW and ANSYS — begins with importing the CAD model into Workbench. The production-intent parametric CAD model of the brake assembly incorporates component-level models such as the pad assembly, caliper, rotor and knuckle. Additionally, the component models are created to incorporate manufacturing variability. After the initial import, the software automatically detects and performs setup for the contacts or joints between parts of an assembly. ANSYS meshing technology then provides multiple methods to generate a hex-dominant mesh or a tet mesh, depending on analysts' requirements.

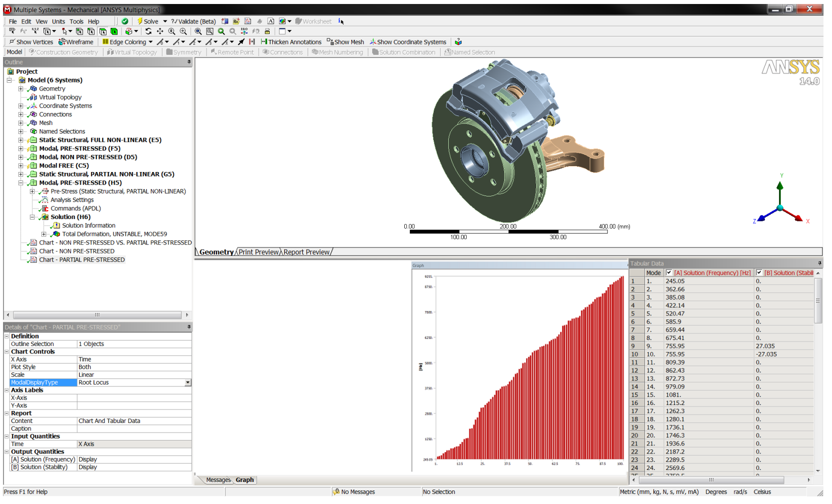
Successfully simulating brake squeal then requires capturing the linear behavior of the structure based on its prior linear or nonlinear pre-loaded status. The TRW team uses linear perturbation analysis to solve a linear problem from this pre-loaded stage — a process that is essentially automated in ANSYS Mechanical. Next, engineers employ a nonlinear static solution to establish the initial contact and compute the sliding contact between pads and disc. The applied stresses and rotation of the disc create the pre-loaded effect, and friction contact generates an asymmetric stiffness matrix during static structural analysis.

In the second phase of the linear perturbation analysis, TRW engineers perform a QR-damped or unsymmetric modal analysis. The eigensolver uses the unsymmetric stiffness matrix generated in the contact elements and may produce complex eigenfrequencies. The results of a perturbation analysis then show the damped frequencies for each mode number along with the stability or real part of the eigenvalues. When the coupled mode shows a positive real value, it indicates instability in the system that may be a source of brake noise or squeal. The analysis results also include the mode shapes, which often provide useful diagnostic information that helps in changing the design to eliminate instability.

The company is confident that it can substantially improve brake quality while reducing engineering costs and lead time.



Flowchart of linear perturbation analysis



Damped frequencies generated by partial pre-stressed complex eigenvalue analysis. Mode 9 has a positive real component and is a potential source of brake squeal.

DETERMINING ROBUSTNESS OF A PROPOSED DESIGN

Beyond accurately modeling the physics of brake squeal, another attraction of the new simulation method is its ability to perform studies that determine the impact of small variations in variables such as dimensions, material tolerances and loads. These variables change from build to build, and, even though they remain within tolerance limits, there is a chance that they might increase or reduce the amount of noise produced by the brakes. With previous simulation methods, there was no way to know what these effects would be. The new method makes it possible to evaluate the robustness of a proposed design by simulating whether any squeal would occur if hundreds of thousands of brake units were built.

The TRW team used ANSYS Workbench to determine the robustness of a proposed design as an extension of a single simulation. Using ANSYS DesignXplorer, the team performed a design of experiments (DOE) to create a set of simulations that explore the design space with a minimum number of simulation iterations. When TRW executes an “Update All Design Points” in DesignXplorer, the first set of parameter values is sent to the parameter manager in Workbench. This action drives changes to the model from the CAD system to post-processing. TRW engineers then simulate the new design point, and output results are passed to the design point table to be stored.

This process continues until TRW solves all of its design points. DesignXplorer presents the expected output variation so the engineering team can determine whether or not the design meets robustness requirements. If not, the team looks at the sensitivity plot and other charts to determine which parameters need to be adjusted or tightened to obtain the required robustness. This information helps to reveal which tolerances can be relaxed without compromising the design.

VALIDATION

The new simulation approach proved its capability in a series of simulations that the TRW team validated with physical testing. These confirmation studies demonstrated that it is possible to simulate brake noise and other output parameters, such as mode shapes and frequencies, without using physical testing to calibrate the results. Clearly, the new approach can more accurately model the physics behind brake noise than the traditional simulation method. The ability to incorporate manufacturing variation into simulation and predict what proportion of builds will squeal is another major advantage.

TRW is moving to implement the new method into its design process for future brake programs. The company is confident that it will be able to substantially improve brake quality while reducing engineering costs and lead time.